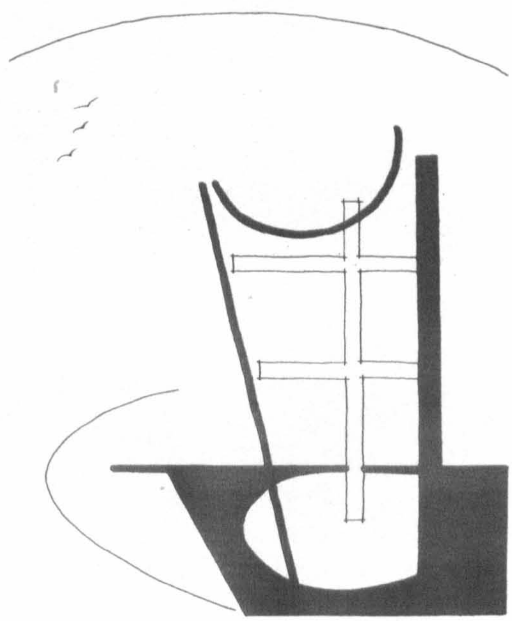
PROCURING THE URBAN HOUSE IN PARADISE

Charles Roy Smith



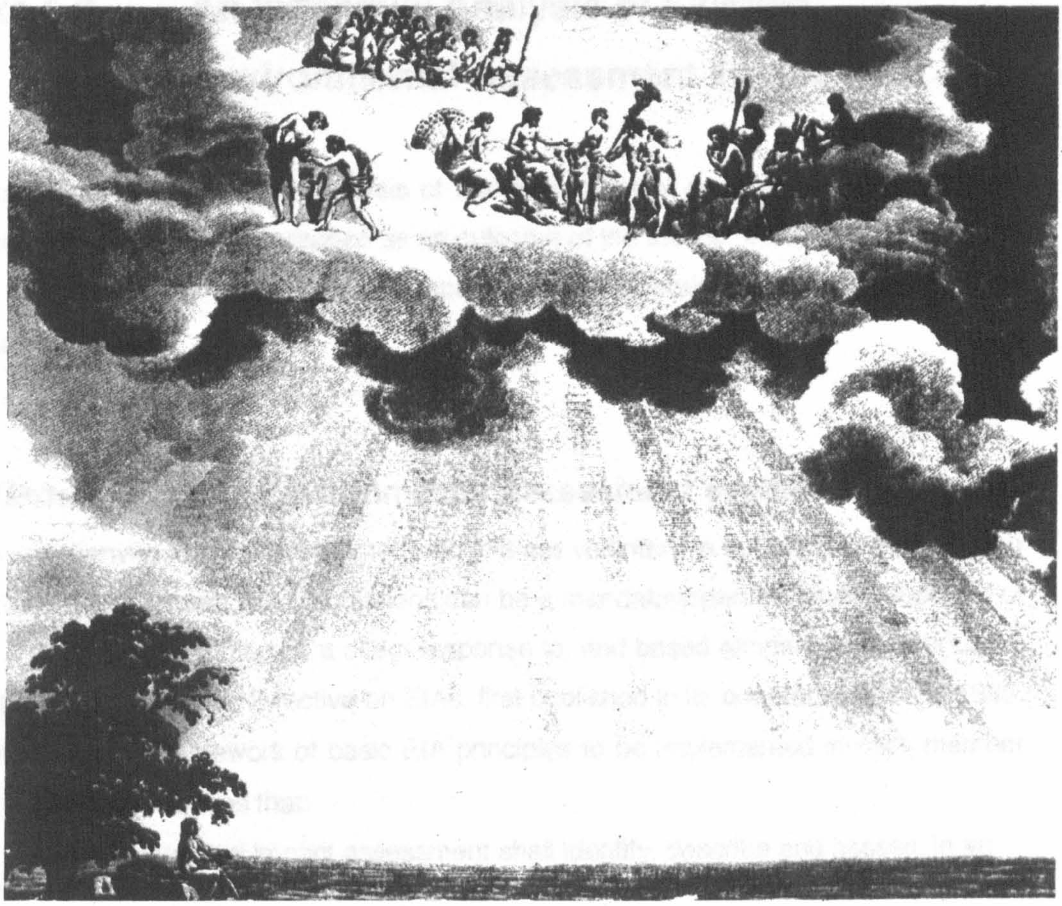
Volume 3 - Annexes

Contents Volume Three - Annexes

Annexe 1.0	An Individual Analysis of Existing Environmental Assessment Techniques	3
Annexe 2.0	The Criteria for the Tool – A Detailed Summary	26
Annexe 3.0	Benchmark Analysis of the Criteria	45
3.1	Carbon Dioxide Emissions: Inhabitation	48
3.2	Carbon Dioxide Emissions: On Site Construction Processes	60
3.3	Carbon Intensity: Space and Water Heating	63
3.4	Construction Period	66
3.5	Contextual Significance of the Site	70
3.6	Deconstruction and Demolition: Recycling of Materials	73
3.7	Density: Quantitative	78
3.8	Density: Qualitative	86
3.9	Design Life Span	89
3.10	Diversity	95
3.11	Domestic Waste Recycling	99
3.12	Ecological Significance of the Site	105
3.13	Ecological Weight: Embodied Energy	111
3.14	Ecological Weight: Embodied CO_2 Emissions	119
3.15	Energy Consumption: On Site Construction Processes	122
3.16	Energy Consumption: Inhabitation	125
3.17	Energy Generation: Inhabitation	136
3.18	Green Space	142
3.19	Lifecycle Cost	147
3.20	Nitrogen Oxide Emissions from Gas Boilers	162
3.21	Other Ecological Impacts of Materials	166
3.22	Other Greenhouse Gas Emissions	172
3.23	Pollution: Energy Consumption Inhabitation	179
3.24	Procurement Strategy	185
3.25	Quality of Internal Environment: Indoor Pollution	193
3.26	Quality of Internal Environment: Daylight	199
3.27	Quality of Internal Environment: Ventilation and Air Tightness	203
3.28	Reduction and Recycling of Construction Waste	215
3.29	Recyclability of Building: Adaptability	219
3.30	Space Standards: Area	224
3.31	Space Standards: Volume	237
3.32	Thermal Performance	241
3.33	Use of Recycled Materials	253
3.34	Use of Renewable Raw Materials	259
3.35	Utilisation of Local Resources	262
3.36	Water Consumption: Construction	265
3.37	Water Consumption: Inhabitation	268
Annexe 4.0	Criteria of the Urban Housing Design and Procurement Database	280
Annexe 5.0	Prioritising the Criteria for the Tool	297

5.1	Contribution to the Reduction of the Greenhouse Effect	300
5.2	Contribution to the Reduction of Pollution	336
5.3	Contribution to the Reduction of Natural Resource Consumption	358
5.4	Contribution to the Reduction of Ozone Depletion	390
Annexe 6.0	Completed Validation Questionnaires	408
Annexe 7.0	Research Papers	419

Annexe 1



An Individual Analysis of Existing Environmental Assessment Techniques

Annexe 1.0 An Individual Analysis of Existing Environmental Assessment Techniques

This annexe contains a detailed analysis of the most relevant comparative environmental assessment methods to that envisaged as an outcome of the thesis. It is from this individual analysis that the overall appraisal in chapter 2.0, An Appraisal of Existing Modelling Techniques, is based.

1.1 United Kingdom Environmental Assessment system

Whereas other environmental assessment models are voluntary in the United Kingdom, the Environmental Assessment (EA) regulations can be a mandatory part of the development of a project. They were instituted as a direct response to, and based almost to the letter upon, the European Commission's Directive on EIAs, first published in its adopted version in 1985. It provided a flexible framework of basic EIA principles to be implemented in each member state. The Directive requires that:

> ... the environmental impact assessment shall identify, describe and assess, in an appropriate manner ... the direct and indirect effects of a project on:
> - human beings, fauna and flora,
> - soil, water, air, climate and the landscape,
> - the interaction between the[se] factors ...,
> - material assets and cultural heritage.[1]

A screening process was also evolved to determine which projects should be subject to EIA, by virtue of size, nature or location. In the United Kingdom EA projects are divided into two categories: Schedule One, of projects to which require an EA in every case, and Schedule Two, of projects to which an EA may be required dependent upon significant effects upon the environment. An urban housing project would never fall into Schedule One. An appendix includes projects to which an EA may be appropriate; it states that in urban areas, an EA is not required on previously developed land unless the project is of a much greater scale than the previous use of the land. Also, an EA may be required if the site is within an urban area and has not previously been intensively developed, where the site is more than five hectares or there are significant numbers of existing dwellings in close proximity to the

[1] Wood, Christopher. *Environmental Impact Assessment – A Comparative Review*, London: Longman Scientific & Technical, 1995.

site.[2] The new Directive, issued in 1996, does reduce the size of projects that are to be considered down to individual buildings, although these are only large-scale buildings, such as retail centres and entertainment complexes.

Within the Directive, the general nature of the content of the EIA is specified, and it establishes a minimum level of information to be provided:

- a description of the project comprising information on the site, design and size of the project
- a description of the measures envisaged in order to avoid, reduce and, if possible, remedy significant adverse effects
- the data required to identify and assess the main effects that the project is likely to have on the environment
- a non-technical summary

In addition, where the individual member states implementing the Directive consider it necessary, the following can also be demanded:

- baseline environmental conditions
- likely significant environmental effects of the project:
    - direct
    - indirect/secondary/cumulative
    - short/medium/long term
    - permanent/temporary
    - positive/negative
- of mitigating measures
- indication of difficulties encountered in compiling the information[3]

Whilst the United Kingdom EA is unlikely to be applicable to an urban housing project, it provides one context of which the ecological impact of a project is thought to have been considered. In this sense, it can provide one foundation on which to build a matrix of assessment for the urban house in paradise. The definition of what constitutes the environment of the United Kingdom EA does not overtly include the social and economic environment, which the house in paradise matrix does seek to do. The EA is very generalised in its definition, through the need to be appropriate to a diverse range of project types; therefore it could only be considered as a very generalised foundation, predicated on the specific direction of assessing the ecological footprint.

---

[9] Department for the Environment, *Environmental Assessment - A Guide to the Procedures*, London: HMSO, 1989.

1.2 The *Environmental Standard - Homes for a Greener World* and *EcoHomes*

The Building Research Establishment Environmental Assessment Methods (BREEAM) are quantified models that aim to determine the overall environmental impact of a variety of building types, including a model predicated to housing.[4] This was first published in 1991, and in 1995 was superseded by the *Environmental Standard* award.[5] It aims to provide a model for assessing new single household dwellings in terms of the impact on global atmospheric pollution, the local environment, resource depletion, internal environment and the impact of climate change, taking into account building materials, products and process of construction.

Each dwelling design is assessed against a set of criteria; the assessment considers each criterion in its own right, without relation to any others, as opposed to an element within a holistic framework. A 'score' is then attributed through a system of accreditation, based on compliance with a pre-set agenda. For example, for some of the criteria, such as CO_2 production due to energy consumption, the BREEAM model provides quantitative values that could be interpreted as benchmarks. The *Environmental Standard* document proposes criteria which could be included in future versions of the assessment model, such as: the energy, and associated CO_2 emission, content of building materials, the use of renewable energy sources, lifecycle material/energy requirements, external appearance - aesthetics, density, and ventilation effectiveness.

Concerns over the scope and accuracy of the *Environmental Standard* model have been identified. Amongst these are omissions in regard to the embodied energy in the production of building materials and the erection of the building, and the reliability of some of the data included. In addition, the model has no holistic appraisal of the lifecycle of a project, from extraction of materials, through construction and inhabitation, to deconstruction or demolition.[6]

As identified above, the model provides no crossover of information between the criteria. In

---

[3] Wood, Christopher. Op. Cit., p. 39.
[4] Prior, J. J., G. J. Raw and J. L. Charlesworth. *BREEAM/New Homes - Version 3/91 - An Environmental Assessment for New Homes*, Garston: Building Research Establishment, 1991.
[5] Prior, J. J. and Paul B. Bartlett. *Environmental Standard – Homes for a Greener World*, Garston: Building Research Establishment, 1995.

terms of assessing the criteria against a common scale, the *Environmental Standard* model does acknowledge that it would be possible to use a common unit of measurement, and proposes cost, but goes on to identify difficulty in assigning economic cost to, for example, health and climate warming. The matrix of the assessment of the criteria of the 'urban house in paradise', as oppose to quantifying each benchmark in terms of a common unit of measurement, proposes to create an integrated model that creates the crossover the *Environmental Standard* model lacks, but retaining individual units of measurement. As identified previously, it is important to define what each benchmark is being measured against; the consequential effects will be quantified in the unit of measurement specific to that criterion.

The criteria within the *Environmental Standard* are divided into three groups: Global issues and use of resources, local issues, and indoor issues. In order to ensure a sufficient breadth of reduction in the environmental impact of a dwelling achieving the award, compliance requires that a mandatory number of criteria from specific categories have to be fulfilled; the basic requirement is five global and one indoor criteria.

Another criticism that can be made of the *Environmental Standard* is that it does not give any significance to the criteria that are analysed; no emphasis is attributed to the more critical criteria. Some, such as carbon dioxide emissions arising from energy consumption and the use of recycled materials in construction may provide significantly greater benefits to sustainability than others, such as the storage of recyclable materials and the inclusion of a house logbook. It is only in a geographical sense, from the grouping of the criteria, that the *Standard* identifies distinctions between them. Therefore, of two projects with the same number of credits, one might be more sustainable than the other.

In May 2000, during the period of the research, the Building Research Establishment launched the *EcoHomes* assessment model for dwellings.[7] This was a re-issue of, and superseded, the *Environmental Standard*, and like the *Standard* is a version of BREEAM for dwellings. *EcoHomes* considers broad environmental concerns of climate change, resource use and impact upon wildlife; issues are grouped into seven categories for assessment: energy, water, pollution, materials, transport, ecology and land use, and health and well-being. However, like the *Environmental Standard*, the assessment is still feature specific,

---

[6] Golton, Bryn. 'Sustainable Development, the 'Green' Agenda and Building'
[7] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.

and is based upon acknowledging the inclusion of attributes that are considered to improve the ecological sustainability of a project.

One advance that *EcoHomes* has made over the *Environmental Standard* is that, like *Envest* considered below, it uses Ecopoints to quantify the performance of the assessed building; these are a unit of measurement developed by the Building Research Establishment. An Ecopoint is a single unit measurement of environmental impact;[8] 100 Ecopoints equates to the equivalent impact of one citizen of the United Kingdom over one year. A score is determined by dividing the impact, for example CO_2 emissions, by the CO_2 emissions arising from the average UK citizen over one year;[9] this value is then multiplied by a weighting to give an Ecopoint score.[10] Other impacts included in the Ecopoint scoring are: acid deposition, ozone depletion, pollution, and resource depletion. However, Ecopoints are a very abstract unit; they give little indication of the actual environmental impact that a building with a certain score will have. It is a specific intention of the thesis to develop a method of assessment that quantifies a dwelling's impact, through benchmarking, rather than presenting it in an abstract form. They also give little incentive, over creating more environmentally sensitive buildings, to reduce the score; whereas showing energy consumption in standard units will demonstrate the potential cost savings in addition to environmental ones. This may be of significant value in persuading clients to adopt higher performance standards. However, the approximate nature of the operational energy calculation by *Envest* may render quantification in real units difficult.

There are shortcomings in the assessment that were present in the *Environmental Standard*. For example, energy consumption is only quantified through consequent CO_2 emissions; the wide variety of emission factors for different fuel types means that a dwelling with space and water heating fuelled by gas could consume more than double the energy of one fuelled by electricity and achieve an equal rating. Therefore although assessing a dwelling both in terms of energy consumption and CO_2 emissions might initially be perceived as double counting, this demonstrates the value in doing so.

---

[8] Dickie, Ian and Nigel Howard. "Assessing Environmental Impacts of Construction – Industry Consensus, BREEAM and UK Ecopoints', *BRE Digest 446*, London: Construction Research Communications Limited, May 2000.

[9] The impacts from one citizen are determined by dividing the national emission values by the population of the country. Clearly these values will need to be updated periodically as the population increases and emissions change; in the case of greenhouse gas these should fall. This process is proposed to be conducted once every two years.

The majority of the criteria used in the EcoHomes assessment are the same as those in the Environmental Standard; however, the performance required to achieve equal recognition is more stringent. For example, the assessment of CO_2 emissions has become more accurate, and instead of awarding maximum recognition for a dwelling causing 50 $kgCO_2.m^{-2}.a^{-1}$, the assessment awards its lowest rating for that level, rising to a maximum recognition for net emissions of 0 $kgCO_2.m^{-2}.a^{-1}$. The assessment of water consumption has also become more accurate, and is based on predicted actual consumption, as opposed to acknowledging the inclusion of efficient appliances.

Although the BRE propose that the assessment can be made at any stage in the design process, the evaluation is undertaken by an external assessor, and therefore limits the applicability of the assessment as a design tool.

1.3 Envest

In May 2000, shortly after the release of *EcoHomes*, the BRE launched the *Envest* assessment tool. Although predicated on office buildings, *Envest* is included here as it provides one of the most advanced comparatives for the assessment tool envisaged for the 'urban house in paradise'. In the format of a piece of computer software, it enables a designer, at an early stage in the design process, to make informed decisions on the environmental performance of the building.

Envest is an assessment of the environmental impacts of the materials used in construction, and of the energy and other resources consumed over the building's life span. The programme minimises the time taken to undertake an initial, broad-brush assessment by using default values, which can subsequently be updated to provide a more detailed analysis; defaults are based on the level of performance required to acquire Building Regulation approval. The material specification can be varied via on-screen menus, and the thickness of materials altered. In terms of servicing, there is a choice of basic services specification, covering heating, lighting, ventilation, water, refrigeration, lifts and catering. These can also be varied with the options provided on menus; for example the wattage of lights and the switching mechanism can be changed. However, restricting the selection to

[10] By way of example, one ecopoint is the equivalent environmental impact of: 320 kWh of electricity, 83 cubic metres of potable water, 65 miles by articulated truck, 1.3 tonnes of landfill waste,

those on menus means a degree of limitation is inevitable; for example, only two types or air conditioning are included. As a consequence of this the operational energy calculations are approximate. For this reason, *Envest* is not intended as a replacement for BREEAM for offices, which is conducted by trained assessors and provides a much more accurate calculation of operational energy consumption.

One of its specific aims was to draw attention to the significance of embodied, as well as operational, environmental impacts.[11] The embodied energy assessment in *Envest* is based upon the quantity of materials used in one square metre element, for example wall or roof, and that is multiplied by the area of that element in the building being assessed. The shortcoming of this method is that the embodied energy level is not based on the actual quantity of material in the specific building being assessed, but on the material in a typical square metre of masonry construction or rain screen cladding, and may not therefore be as accurate. Its advantage, however, is that it gives a quicker assessment.

To determine the lifecycle energy consumption of the building *Envest* multiplies the annual energy consumption during occupancy by its predicted life span,[12] this is then added to the embodied energy of the materials to produce a total. The consequence of this calculation is that if all else remains equal, the lower the predicted life expectancy of the building the higher the score obtained. This is contradicts its original intention of drawing attention to the significance of embodied impacts, and could be interpreted as encouraging buildings with shorter life spans as they are more environmentally benign; which might a detrimental impact on the longevity of buildings. In his essay 'The Generic City' Koolhaas proposes that the hotel will increasingly provide accommodation, implying greater temporality and less permanence.[13] However, is increased temporality reflected in the cultural history of dwelling, and in minimising environmental impact? It is not true of the colloquialism 'an Englishman's home is his castle', which implies solidity and permanence. Also, if architecture considered as a representation of man's presence through time, and buildings, including dwellings, are a part of the culture, spirit, theories and materials of the age, reducing longevity will hasten the obliteration of that representational legacy. Clearly, shorting the life span of a dwelling minimises the efficiency of the materials from which it is

---

manufacturing 750 kg of, or 250, bricks, or 1.38 tonnes of mineral extraction.

[11] Interview conducted with Jane Anderson of the Building Research Establishment's Sustainable Construction Unit, 16 August 2000.

[12] A default value of 60 years is assumed, but this can be varied.

[13] Koolhaas, Rem. 'The Generic City', in Koolhaas, Rem and Bruce Mau. *S, M, L, XL*, Rotterdam: 010 Publishers, 1995.

constructed, which can account for 10 percent of the energy consumed over the life span of a typical dwelling.

1.4 Housing Quality Indicators (HQIs)

The Housing Quality Indicators were developed by the architects DEGW on behalf of the Department of the Environment, Transport and the Regions and the Housing Corporation. The intention was to include measures of quality in the assessment of procedure for funding, broadening the focus from the traditional attention on cost and regulatory standards, thereby ensuring that publicly funded housing achieves the best value for money, in a wider concept of value. Although applicable to any housing development, the evolution in partnership with the Housing Corporation and piloting the Indicators with social housing providers has lead to a focus to public sector rather than private sector housing.

The HQIs are based on location, design and performance of the project. The assessment views the dwelling not just as an isolated entity, but as part of a wider development including context and surroundings. It was seen as important to relate dwelling design both to the way in which people wish to live and to the context in which the dwelling is located, and not just considering the dwelling itself. It is envisaged that the HQIs can be applied at any stage of the design process. At the feasibility stage HQI scores can be used as an incentive to meet a particular standard, and subsequently that these targets will ensure that design and construction decisions take account of quality; however, that would be quality only as defined by the HQIs themselves, and might not include a wider scope of value. Due to some of the indicators being dependent upon post completion analysis, such as the Performance in Use Indicator and noise reduction in the Unit – Noise, Light and Services Indicator, the final HQI score can only be determined after the dwelling has been completed and occupied. A shortcoming of the score being dependent upon post completion analysis is that by the time such analysis can be made, it may be too late to improve the performance; this is intended to be overcome in the interim period by such Indicators acting as design and construction quality targets.

Mandatory requirements have served as contributors to the material in the indicators; the Standard Assessment Procedure (SAP), Building Regulations, Secured by Design, and BREEAM have all informed the evolution of the assessment method. However, the HQIs themselves do not aim to set out minimum standards, but to provide assessment within a range of standards. The notion that standards can continually be improved upon is an integral part of their structure.

There are ten Quality Indicators in an assessment. Each of these is scored independently, and a final aggregate score, expressed as a percentage, used to determine the project's overall performance. The performance profile across the ten Indicators is given to communicate particular strengths and weaknesses over the individual assessment areas. Each Indicator receives one tenth of the total possible aggregate score, because it was considered that they all could be viewed as equally important in creating quality. Based on a percentage, dependent upon the inclusion of certain attributes, the assessment is feature specific for many of the criteria; it is a relative and not absolute measure of performance. The ten Indicators, and the sub-criteria that are used in their assessment, are given below:[14]

Location:
amenities, retail, schools, play and leisure, public transport, absence of liabilities, absence of noise sources

Site – layout and landscaping:
visual impact, layout, landscaping

Site – open space:
site security, shared areas in flats, children's play areas, private open spaces/gardens, car parking

Site – routes and movement:
routes and movement, access to the unit

Unit – size:
area, number of living spaces

Unit – layout:
furniture spaces, access, passing and activity zones, additional desirable features

Unit – noise, light and services:
noise reduction, quality of light, aspect and prospect, standard provision of service, additional desirable services

Unit – accessibility:
accessibility within the unit

Unit – energy and sustainability:
energy use, standards and features, sustainability, standards and features

Performance in use:
durability, adaptability, Secured by Design, user satisfaction and post occupancy evaluation

The interface with the assessment method is in two parts. The first is in paper form; a booklet is used as the basis to analyse a project to determine the performance under each Indicator. This data is then entered onto a computer spreadsheet to determine the

[14] Department of the Environment, Transport and the Regions website, 22 August 2000: www.detr.gov.uk/housing/information/hqi/index.htm

performance profile for the ten indicators, and the overall aggregate score. There is not a computer software version that integrates the completion of the HQI form, identifying how a project performs against the assessment criteria, with the scoring spreadsheet; however this is seen as being advantageous, and a potential development in the future.

Within the HQI assessment there are some contradictory or incomplete measures. For example, when considering the provision of car parking, the basis for assessment is that the higher the provision the higher the score awarded; this would appear to be at odds with sustainable development where, with adequate provision or availability of alternative modes of travel such as public transport, a reduction car use, and consequent pollution, would seem to be more in harmony with a reduction in car parking provision.

Also, the energy performance of the dwelling is measured on the basis of the SAP score, which has limitations. For example, whilst it accounts for the incidental gains from lighting and appliances, the assessment takes no account of the energy that these consume, and therefore is not a true representation of the energy that the dwelling consumes. Furthermore, because the SAP rating is based on both energy consumption and energy cost, the fuel cost per unit can affect the outcome. This can lead to unusual effects; for example, if the consumption remains constant, but the fuel source is switched from off-peak electricity to on-peak, the SAP score will fall; this will be interpreted by the HQI as a reduction in the energy efficiency of the dwelling, which has in reality remained constant.

During the pilot testing of the HQI assessment, conducted by a number of Registered Social Landlords, one felt that it under emphasised flats, particularly on urban brownfield sites, in favour of greenfield housing development. This leads to the possibility of penalising urban housing through a reduced score, merely by virtue of the nature of the urban environment.[15] This is clearly at odds with the current Government drive to locate 60 percent of new housing on brownfield land, with a significant proportion in urban areas, and to discourage greenfield development.

A significant number of the Indicators include criteria that are subjective and based on the opinion of the assessor; this would be expected in an assessment based on the concept of quality. The assessment of such criteria is typically based on whether they are considered 'good', 'average' or 'poor'. The shortcoming of this methodology was highlighted in the

---

[15] Ibid.

piloting, during which different assessors rated the same project with different scores.[16] Yet in performance assessment continuity and consistency should be prerequisite.

In conclusion, a number of the RSLs that participated in the pilot testing considered the HQI assessment to be too cumbersome and time consuming to use if it were to become a mandatory requirement, due to the time and effort required to assess individual schemes. This nature of response has an impact on the potential application of any assessment tool, regardless of whether it is proposed to become a mandatory test. Any assessment should be appropriate to use on any project; otherwise its application will be discouraged and any benefit that it may give on the performance of a project will be lost.

1.5 The Dutch Environmental Preference Method

The Environmental Preference Method (EPM) was developed in 1991, within the framework of the Dutch SEV's (Steering Committee on Experiments in Housing) experimental programme on sustainable living, 'Schoner Wonen.' Its aim is to provide a tool for comparative assessment of environmental impact of materials and products used in both construction and refurbishment, during the design process. Over half of the Dutch local authorities use the EPM in drawing up guidelines, and it is used as an evaluation tool in seven EU member states.

The EPM compares materials and products for each element or application in the construction and refurbishment process, and ranks them according to environmental impact; the outcome is not an absolute, valued environmental impact assessment, but rather a scale of preference. Based on the structure of the Life Cycle Assessment (LCA), developed by CML Leiden in the Netherlands, consideration, is given to the whole life-cycle of the material or product, from extraction, through production, building, occupation, to decomposition. The principle criteria considered in the assessment are:[17]

- shortage of raw materials
- ecological damage caused by extraction of raw materials
- energy consumption at all stages (including transport)
- water consumption
- noise and odour pollution

[16] A number of the RSLs involved in the pilot testing were keen that subjective issues, such as site and aesthetics, were retained in the assessment.
[17] Anink, David, Cheil Boonstra and John Mak. *Handbook of Sustainable Building - An Environmental Preference Method for Selection of Materials for Use in Construction and Refurbishment*, London: James & James, 1996, p. 8.

- harmful emissions
- global warming and acid rain
- health aspects
- risk of disasters
- reparability
- waste

The procedure of the EPM contains four steps, based on those of the LCA:

- **goal definition**: determine available alternatives
- **inventory**: of the environmental effects of each alternative, in both quantitative and qualitative terms
- **classification**: into five main environmental aspects: resources, energy, emissions, damage, and waste
- **evaluation**: through a matrix based on the classification above, to determine the environmental preference. There is no fixed weighting of the scores for each aspect, as relevance is not the same for each application and therefore cannot be cross-referred

Considerations such as cost and aesthetic value do not have any implication in the EPM assessment or preference rating, which will become criteria within the matrix of the 'urban house in paradise'. However, the development of the EPM model, in terms of new construction projects, was based on several experimental trials, in both the Netherlands and Germany, and most of the pilot studies were based on the requirement of achieving sustainable building within existing budgets.

The EPM concentrates on the environmental effects arising from the choice of materials of construction and renovation; within the occupation phase of the life-cycle, the model considers only effects on health and quality of the indoor environment, it does not take account of pollution that arises from the inhabitation of a dwelling in terms of water and energy consumption. The method is intended to be complimentary to models such as BREEAM, that consider the implications of the building in use in terms of, amongst other criteria, energy consumption, waste and pollution.

1.6 Danish Manual on Environmental Management in Project Design

Developed on behalf of the Danish Environmental Agency the Manual on Environmental Management in Project Design aims to establish common guidelines for environmental management in project design of building and construction work. The process recognises that environmental impacts should be evaluated over the life span of the project, although acknowledges that this lifecycle appraisal is a new area of study. It also stresses that reducing environmental impacts is most successfully achieved at the brief and design stages; that it must add new aspects to a project and the basis for decision-making during the project. In this way, environmental planning should be integrated into work typically associated with defining a project and designing its solution.[18] In terms of responsibility the majority falls on the contractor, who is required to have sufficient understanding to formulate an environmental policy, and to assist in formulating environmental targets.

The Manual provides a working methodology for environmental management; it is based upon three fundamental concepts; environmental impacts, environmental effects and remedial or preventative measures. An environmental impact is any impact the building has upon the environment during its construction and life span; in short the resources consumed and pollution or waste emitted from the building throughout its lifecycle. Environmental effects are the visible consequences of environmental impacts on resources, human health and the external environment. The criteria proposed by the Manual are:

Materials: energy, through fossil fuel consumption
raw building materials, in particular non-renewable
water

Emissions: to the atmosphere
to water
to earth, contamination
solid waste

Health effects: poisoning
cancer
reproduction and birth injuries
injuries to nervous systems
accidents
physical attrition
hearing damages
psychological stress
headaches
rashes
allergies and hyper-sensitivities
respiratory disorders
lack of comfort

Environment effects: greenhouse effect
destruction of ozone layer
smog formation
acidification
deterioration of habitat
loss of biodiversity
toxic impacts on air, aquatic environment and soil

As the criteria are aimed to encompass impacts arising from the construction of any

[18] BPS. *Manual on Environmental Management in Project Design – Methodology Description*,

structure, they are very generalised, and the Manual recognises that a process to scope them into those relevant to each specific project should precede their incorporation into the management strategy. A significant attribute of the methodology is that it recognises the importance of considering the impacts and effects arising from the building or structure throughout its lifecycle.

1.7 Eco-Quantum

Developed by the IVAM in Holland, Eco-Quantum is an environmental assessment method based on a lifecycle assessment of materials. Rather than the EPM, which suggests preferences for materials for various elements in the construction process, Eco-Quantum calculates a score based on the environmental impact of the materials used. The assessment covers the environmental consequences of material choices and water and energy consumption. The assessment uses two independent programmes to determine the impact of materials used, and the energy consumption of the dwelling; however it does not create automated linkages between these two fields.

To reduce the time taken to conduct an assessment, standard environmental impact profiles are used for different construction methods. As a consequence of which, the assessment of a dwelling is based on the assumed quantity of material for each given construction element, rather than basing the assessment on the actual total quantity of material from which the dwelling is constructed, and will consume additionally during maintenance throughout its life span.

The scoring of a dwelling by Eco-Quantum is based upon eleven environmental effect scores, rather than quantifying the performance in absolute terms, in a form such as energy consumption in $kWh.m^{-2}.a^{-1}$ or embodied energy in $kWh.m^{-2}$; the effect scores include raw material depletion, and ecotoxicity. The effect scores are then converted into four environmental indicators: raw material depletion, emissions, energy consumption and waste. These four indicators are used as the basis for comparing the performance of one dwelling against another.

Taastrup: BPS-Centre, 1998.

1.8 BEPAC

The Canadian Building Environmental Performance Assessment Criteria (BEPAC) programme was initiated in Canada in 1993, and is predicated toward the assessment of new and existing office buildings. The criteria are structured into five primary 'environmental topics': ozone layer protection, environmental impact of energy use, indoor environmental quality, resource conservation, and site and transportation. Each topic contains a series of criteria, and these, if required, can be divided further into sub-criteria. A total of seventy-five building criteria and sub-criteria create the complete model; both quantitative and 'feature specific' criteria are adopted.

The basis for each evaluation is the standard achievable by best practice methods. Each criteria is evaluated on a point scale, valued between one and ten; for criteria divided into sub elements, the ten points are divided among them. Points awarded are on of three types: in some 'feature specific' criteria, full points are awarded for the presence of the feature, or for compliance with a threshold value; a scale of points is awarded for criteria based on a continuum, such as ventilation rate; the points award increase as the effort to achieve them increases, according to a prescribed algorithm; upper limits of performance demand a ten point score, for example zero ozone depletion substance, whilst compliance with current standard practice scores zero.

An attempt is made to recognise the relative significance of different criteria, through weightings placed on the point assessed to reflect its significance, or its priority relative to other criteria within the same topic area. The relative weightings for the criteria were derived through filtering them through a set of relative considerations that indicate their relative importance, scale and urgency in global and health terms. The total weighting for each specific section, for example environmental impact of energy use, is always 1.00; that value is then broken down attributing each criterion under that topic with a relative significance. Evidently, this means that criteria can only be compared with others under the same topic; it was considered that, given the fundamental differences between topic areas, it was not desirable to apply weightings between them. The weightings for the criteria were derived by considering them against a set of conditions, specific to each topic, that assessed their importance, scale and urgency in both global and health terms.[19]. The programme ultimately assigns a value calculated through the multiplication of the point of each criterion by its weighting. Therefore comparatives can be drawn between criteria

[19] Ibid.

within each of the five topics; it was not deemed meaningful, or possible, to apply weightings between the topics, due to their differences.

A disadvantage of BEPAC, is that by breaking all of the criteria down into five independent categories, and weighting those categories individually, without the potential for comparison between them, the opportunity for a holistic output is diminished. This focuses attention away from the notion of environmental performance being a holistic, interrelated concept, when that is a fundamental quality of sustainability.

1.9 Green Builder Program - Residential

The Green Builder Program was initiated in 1992 for residential buildings in Austin, Texas. Criteria are structured into four primary 'resource issues':

- Water
  - indoor water use
  - outdoor water use
- Energy
  - solar heating and cooling: mechanical system
  - solar heating and cooling: thermal envelope
  - lighting, appliance and general electrical needs
  - water heating
- Materials
  - structural frame
  - foundation
  - floor
  - walls
  - window, door and trim
  - roof
  - finishes and adhesives
  - insulation
- Solid Waste
  - solid waste: in plot
  - solid waste: within the dwelling

Each topic area contains a total of 135 assessed building features, evaluated against seven categories of criteria. Points are applied through a separate protocol to establish the relative 'sustainability value,' by referencing six categories: source, process, use, recycle/disposal, integration and difficulty; each of these contain a series of performance, each of which are, typically, assigned one point. The resultant total is then multiplied by a seventh 'use factor.' The Green Builder Program is notable in that it is the only assessment model that acknowledges and incorporates the notion of linkages between the criteria, i.e. the creative integration of environmental strategies in the assessment.

1.10 Factor Four

As oppose to an environmental assessment model, Factor Four represents a philosophy for more sustainable development; it can be interpreted as a standard through which to judge an increased level of resource productivity, and therefore can be looked upon as a benchmark, hence its inclusion.

> 'Factor Four,' in a nutshell, means that resource productivity can - and should - grow fourfold. The amount of wealth extracted from one unit of natural resources can quadruple. Thus we can live twice as well - yet use half as much.[20]

In other words, Factor Four presents the philosophy and precedents for doubling the standard of living whilst halving resource use, or equally, to maintain the current standard of living whilst consuming a quarter of the energy and materials that we currently do. The benchmark of Factor Four could be used, for example, as a measure of the resource efficiency of a dwelling, to ensure that the use of resources, such as energy, is aimed at being at least four times as efficient as current practice does at present. Factor Four, and increased resource productivity, requires integration of parts to create a significantly more efficient whole. Therefore, as a reflection of such integration, the matrix to measure such efficiency should consider all of the parts as an integrated whole, as oppose to individually, as BREEAM and the Dutch EPM models do.

1.11 The Absolutely Constant Incontestably Stable Architectural Value Scale

In 1971, the American architect Malcolm Wells argued that human values are so unstable that objective comparatives are meaningless. He advocated that only the wilderness, and specifically the *forest*, that existed in a particular place prior to human development can provide an absolute measure of the success of a work of architecture:

> We seem to have no base other than man-centredness from which to measure our works. Our value criteria are so unstable that nothing can be objectively compared with anything.
>
> But there is a way to evaluate what we do. There's a cold, scientific, stable,

[20] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998, p. xiix.

> constant, absolute and very simple scale on which we can measure not only architecture, landscape architecture, engineering and planning, but also ... everything else that's likely to effect the environment of which we are so visibly a part.[21]

Wells draws a direct comparison between the wilderness and the city, on the basis that both have the same goal: sustenance of a successful living community on the land. The wilderness is very likely the ideal solution to a particular environment, an ideal paradise that can be used as an unchanging standard against which to measure solutions to the same issues and goals. Perhaps the notion of the *forest* can be related to Vitruvius' account of the creation of the first dwelling house, the origin of the concept of dwelling, within a clearing within the forest. Vitruvius' clearing was both a literal and metaphorical counterpoint to the forest; a clearing created through the unsustainable destruction of the forest, an edge that is defined in terms of the relationship between the human and natural environments.

> The edge of Vitruvius' clearing brought about the realisation of spatial differentiation and the consequent valuation of spatial heterogeneity. The contrasts between clearing and forest, between known and unknown worlds, and between sacred and profane places were the essential hierarchical structures that made the world meaningful.[22]

The fire that created the clearing, and the desire to keep it burning to preserve the locus of Vitruvius' 'deliberative assembly,' which constituted the genesis of urbanism and the public consciousness, further depleted the forest and erased it presence.

The fifteen criteria of assessment are an analogy of the attributes of the *forest*: a wilderness that creates pure air, pure water, and all of the food for its inhabitants; it draws its energy from the sun, and creates its own fossil fuels; it consumes all of its own wastes, and it creates silence. Evaluation is made on a scale between -100 and +100; a negative score represents a destructive effect, a positive a beneficial effect. Therefore, the paradisical ideal score is +1500, the least desirable -1500; the *forest* achieves +1500. The scale of assessment has 25 point increments that indicate the frequency with which the subject contributes to the attribute in a beneficial or destructive way, (0 = never, -25/+25 =

---

[21] Wells, Malcolm B. 'Environmental Impact,' *Progressive Architecture*, June 1974, p. 92.
[22] Dripps, R. D. *The First House*, Cambridge, Massachusetts: The MIT Press, 1997, p. 89.
[23] The countries that participated in GBC '98 were: Austria, Canada (who lead the process), Denmark,

occasionally, -50/+50 = sometimes, -75/+75 = usually, and -100/+100 = always). The criteria are:

+100 to +25	0	-25 to -100
creates pure air		destroys pure air
creates pure water		destroys pure air
stores rain water		wastes rain water
produces it own food		produces no food
creates rich soil		destroys rich soil
uses solar energy		wastes solar energy
stores solar energy		wastes fossil fuels
creates silence		destroys silence
consumes its own wastes		dumps its wastes unused
maintains itself		needs repair and cleaning
matches nature's pace		disregards nature's pace
provides wildlife habitat		destroys wildlife habitat
provides human habitat		destroys human habitat
moderates climate and weather		intensifies climate and weather
beautiful		destroys beauty

Subsequently, Wells' framework of criteria was developed and extended by the architect William McDonough into a Matrix of Sustainability, based on the headings:

- Materials
- Land Use
- Urban Context
- Water
- Wastes
- Air
- Energy
- Responsibility

1.12 GB Tool

The Green Building Tool (GB Tool) is one of, if not the, first second-generation environmental assessment models. It is the outcome of a two year development process called the Green Building Challenge '98 (GBC '98), involving international teams from 14 countries lead by the University of British Columbia in Canada;[23] aimed to stimulate debate about the scope and role of the environmental performance assessment of buildings.[24] One of the aims of GBC '98 was to build upon first-generation assessment models to develop a method for assessing the energy and environmental performance which would be tested on

---

Finland, France, Germany, Japan, the Netherlands, Norway, Poland, Sweden, Switzerland, the United Kingdom, and the United States of America.

[24] Cole, Raymond J. and Nils K. Larsson. 'GBC '98 and GB Tool: Background', *Building Research & Information*, Volume 27 Number 4/5, 1999.

a range of case study buildings in the participating countries. This enabled the validation of the assessment framework in terms of the aim to develop an international framework capable of being adaptable to national or regional contexts. GB Tool is an experimental assessment method that is currently under development, and not as yet commercially available. The process was an attempt to identify the correlation between an evolving assessment system and a number of case study evaluations. In terms of its contextualisation to national and regional circumstances, this was achieved by creating a set of core criteria reflecting global issues that were complemented by modifications reflecting energy, environmental issues in specific countries and regions.

The performance categories of GB Tool are resource consumption,[25] environmental loadings,[26] indoor environment,[27] longevity,[28] process[29] and contextual factors.[30] These generic criteria are supported by sub-criteria that are much more specific to an individual building or region.

GB Tool also uses benchmarks as a part of the methodology of assessment. However, these are based upon the values of applicable regulations or industry norms, as opposed to the standards that are achievable in terms of best practice; this was due to a lack of consensus in what constitutes excellence in the environmental performance of buildings.[31] Because of this it could be considered not to provide an incentive for pursing standards significantly higher than the typical performance of industry. Using performance targets of best practice at the limit of technical feasibility would demonstrate to the user the standards that could potentially be achieved. Also, GB Tool uses benchmarks of the actual performance of a building, assessing it after completion. Although this may be more accurate, in that the predicted consumption might not equal that of the actual, it limits the potential for the tool to be used during the design stages to improve performance.

Although GB Tool attempted to embody weighting between its criteria, this was judgement, and left to the subjective opinion of each of the individual teams form the various countries involved. A set of common considerations to be accounted for in deriving the appropriate

[25] Energy, land, water and materials.
[26] Airborne emissions, solid waste, liquid waste and other waste.
[27] Air quality, thermal qualtiy, visual quality, acoustic quality, controllability of systems.
[28] Adaptability and maintenance,
[29] Design and construction process and building operations planning.
[30] Location and transportation and loadings upon immediate surroundings.
[31] Ibid.

weightings was provided;[32] however no methodology for their application was proposed. Although weighting was used in the process of GB Tool, the outcome of an assessment does not make apparent which categories should have priority.[33]

Like the Ecopoints scoring system developed by the Building Research Establishment, GB Tool uses an abstract, dimensionless value to rate the performance of a building, between the value of -2 and +5, with a score of 0 representing the typical industry performance. The lead to the criticism that GB Tool hides, "... the real mass and energy flows which determine effective environmental impact."[34]

[32] This included questions such as: is the effect upon the environment irreversible, is the effect upon the environment long-lasting, what number of people are affected by the issue being covered, does the practice in question have momentum that will require a significant degree of effort to counter? A number of these have a clear anthropocentric bias.
[33] Cole, Raymond J. 'Building Environmental Assessment Methods: Clarifying Intentions', *Building Research and Information*, Volume 27 Number 4/5, 1999.
[34] Ibid.

Annexe 2

The Criteria for the Tool – A Detailed Summary

Annexe 2.0 The Criteria for the Tool – A Detailed Summary

Taking each of the criteria identified in chapter 3.0 individually, the following text gives a brief description of what each of the criteria encompasses in its consideration of the performance of the dwelling. The reasons as to why it has been included within the matrix of criteria that define the 'urban house in paradise' and the sources from which it has been derived are also commented upon.

2.1 CO_2 emissions during construction and deconstruction

The embodied CO_2 values for materials only take account of the emissions arising from energy consumed up to delivery to site. This criterion will be an assessment of the emissions that arise as a consequence of the energy consumed by on-site processes in the construction and demolition of the dwelling. The energy consumed on site was proposed as a potential issue to be considered in future revisions to the *Environmental Standard* assessment;[1] however, the consequent CO_2 emissions arising from this consumption were not included as a potential consideration but unarguably will have other environmental consequences and depending upon the fuels used will vary in magnitude. The criterion was not included within *EcoHomes*, the subsequent revision of the *Environmental Standard.*[2]

2.2 CO_2 emissions during inhabitation

Carbon dioxide (CO_2) accounts for around 87% of the relative contribution of the anthropogenic greenhouse gas emissions in the United Kingdom.[3] Approximately 50 percent of the CO_2 emissions in the United Kingdom can be attributed to energy use in buildings, and 60 percent of this, or 30 percent of the total, can be attributed to the dwelling stock.[4] As CO_2 is produced through the combustion of fossil fuels, the level of emission will

---

[1] Prior, J. J., G. J. Raw and J. L. Charlesworth. *BREEAM/New Homes - Version 3/91 - An Environmental Assessment for New Homes*, Garston: Building Research Establishment, 1991.
[2] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.
[3] West, John, Carol Atkinson and Nigel Howard. 'Embodied Energy and Carbon Dioxide Emissions for Building Materials,' Paper presented at the CIB Task Group 8 conference on 'Environmental Assessment of Buildings,' 16-20 May 1994, at the Building Research Establishment.
[4] Shorrock, L. D. *Future Energy Use and Carbon Dioxide Emissions for UK Housing: A Scenario*, Building Research Establishment, July 1994; and Department of the Environment, Transport and the

be directly related to the energy consumed by the dwelling during the period of its inhabitation, however it will not solely be dependant upon this, which is one reason as to why it has been included as a separate criterion. The quantity of CO_2 emitted for each kilowatt-hour of energy consumed can vary considerably, for example, 0.21 kg CO_2 for gas, and 0.75 kg CO_2 for mains electricity. Therefore the level of emission will also be dependent upon the fuel types used within the dwelling. Due to the significant ecological impact of CO_2 emissions, this will also be a useful indicator of, at least in part, the sustainability of the dwelling.

2.3 Carbon intensity

The level of carbon emissions arising from for space and water heating appliances are affected by the efficiency of the heating system and its control methods, by the type of fuel being used, and also the thermal performance of the envelope; the latter are considered in other criteria. The carbon intensity can therefore be defined as the ratio of total carbon dioxide emissions from the heating system to the total useful heat output for space and water heating, over an annual cycle.[5] It is a measure of the efficiency of the performance of the heating system that takes account of the fuel type that is used; the latter point is significant because the carbon intensity of different fuel types can vary significantly. Researchers at Leeds Metropolitan University proposed that carbon intensity be integrated into future revisions the Building Regulations,[6] and it is therefore relevant in defining the performance of the dwelling.

2.4 Construction period

This is a measure of the time taken to construct a dwelling or a block of dwellings, depending upon the typology. Initially the Construction Task Force,[7] followed by the Construction Best Practice Programme and the Movement for Innovation, identified the construction period for benchmarked reduction principally as a source of reducing construction cost, although highlighting other benefits such as less noise, disruption and intrusion.[8] The Building Research Establishment is currently conducting research into the

---

Regions. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report Number 53*, London: DETR, 1998.

[5] Personal communication from Robert Lowe, Leeds Metropolitan University, December 1999.

[6] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.

[7] The Construction Task Force. *Rethinking Construction*, London: HMSO, July 1998

[8] Construction Best Practice Programme website, 1 May 2000: www. cbpp.org/themes/suscon

effect of the transportation of site workers to and from site;[9] reducing the construction period would lessen impacts arising from this. Both of the Millennium Community competitions, in Greenwich and Allerton Bywater, proposed benchmarked reductions in construction time.

2.5 Contextual significance of the site

This criterion is of critical importance in terms of the retention of cultural heritage. It is of particular relevance due to the predication of the thesis upon urban housing, where the contextual significance of the site is likely to be greater than on a greenfield site. Its aim is to ensure that due consideration is given to the surrounding buildings and urban grain in the development of the project's design.

2.6 Deconstruction and demolition: recycling of materials

The matrix of criteria is concerned with profiling the performance of the dwelling throughout its lifecycle, from construction through inhabitation and then its demolition at the end of that lifecycle. If the 'urban house in paradise' is to be constructed on a site occupied by an existing building, then the recycling of demolition materials can occur at both the start and end of the cycle. The recycling of materials from demolition has two advantages: reducing raw material extraction, and reducing the quantity of material disposed of through landfill or incineration. This criterion will be a measurement of the percentage of the materials that arise through demolition that are recycled. Although none of the existing environmental assessments analysed in Chapter 2, volume 1, or Annexe 1.0, volume 3, included an evaluation of the potential recycling of demolition material, research has been undertaken on this subject both in the United Kingdom and in Europe.[10]

2.7 Design life span

As stated above, the matrix of criteria is concerned with the 'urban house in paradise' throughout its lifecycle, the length of that lifecycle is one of those concerns. The longer the life of the dwelling the more efficient the use of materials and energy, and consequent pollution emissions, that were used in its construction. Also, prolonging the life span of the

---

[9] Personal communication with Suzy Edwards of the Sustainable Construction unit of the building Research Establishment, 5 October 1999.

[10] The majority of input for this criterion and its benchmark has come from research conducted by the Building Research Establishment, notably: Hobbs, G. and R. Collins. 'Demonstration of Reuse and Recycling of Materials: BRE Energy Efficient Office of the Future,' IP3/97, *BRE Information Paper*, Building Research Establishment, February 1997; Collins, R. J. 'The Use of Recycled Aggregates in Concrete,' IP 5/94, *BRE Information Paper*, Building Research Establishment, May 1994; and Lawson,

dwelling will create greater net savings in energy consumption during inhabitation that arise through the increased embodied energy used to improve its thermal performance. The designed life expectancy will have an impact upon the material specification of the dwelling; materials or components with life expectancies shorter than that of the dwelling will have to be replaced, at a financial and embodied energy cost. The life span benchmark will be a design life expectancy for the dwelling, based on data for the life expectancy of the materials from which it is constructed;[11] there are British Standards on the minimum design life expectancy for different building types that can form a baseline value.[12]

2.8 Density: quantitative

The quantitative measure of the density of a housing development is the number of dwellings that occupy a given area of land and is therefore, in effect, a measure of the efficiency of land use. It is recognised that there are critical levels of density required for sustainability, both in terms of providing critical mass of population and the efficiency of land use, which is a finite resource.[13] Density can be measured in a number of ways, such as people per hectare, dwellings per hectare and habitable rooms per hectare. Therefore a critical issue will be to determine the benchmark as one that can be used consistently, and is responsive to issues such as demographic change. The issue of quantitative density also has contemporary relevance, most notably brought about by the recent Urban Task Force report[14] and reissue of Planning Policy Guidance (PPG) 3.[15]

2.9 Density: qualitative

However, density also has a qualitative dimension. In urban locations, the dwelling is likely to be sited within an existing grain of urban fabric. There may be a predominant scale or form to this fabric, to which a response should be considered. Therefore the qualitative criterion of density will consider to what extent the design of a dwelling or project has considered the surrounding density, if it is appropriate.

W. R. 'Design for Deconstruction,' *First International Conference on Buildings and the Environment*, Building Research Establishment, 1994.

[11] Research Steering Group of the Building Surveyors Division and the BRE. *Life Expectancies of Building Components*, London: The Royal Institute of Chartered Surveyors, August 1992.

[12] British Standards Institute. BS7543 – Guide to Durability of Buildings and Building Elements, Products and Components.

[13] Jencks, Mike, Elizabeth Burton and Katie Williams. *The Compact City – A Sustainable Urban Form?*, E & F N Spon, 1996; and McLaren, Duncan, Simon Bullock and Nusrat Yousuf. *Tomorrow's World*, London: Earthscan, 1998.

[14] Urban Task Force. *Towards an Urban Renaissance*, London: E & F N Spon, 1999.

2.10 Diversity

Programmatic diversity is a measure of the range of different functions that are on a site; these are more likely to be prevalent in an urban location, where there is a wider population to support non-residential functions. The criterion is included to encourage a move away from mono-functional housing development, typical of greenfield estates, which encourages car use. Therefore it is a criterion that can have an impact on the wider sustainability of a neighbourhood beyond the scope considered by the matrix of criteria that define the 'urban house in paradise', as discussed in Chapter 3.0, volume 1, by attempting to influence the behavioural patterns of residents. This is a criterion derived by the thesis, influenced by writings of Hans Kollhof.[16]

2.11 Domestic waste recycling

Currently the predominant volume of domestic waste is disposed of through landfill; very little, approximately 6.5 percent,[17] is recycled. Just as for recycling demolition materials, increasing the proportion that is recycled would reduce the volume sent to landfill, as well as the extraction of raw materials that could otherwise be provided by recycled materials. Landfill waste has a number of impacts upon the environment, such as methane emissions that contribute to the green house effect and leachate emission that can cause local pollution and land consumption.

Evidently, the recycling of domestic waste cannot be guaranteed through the design of the dwelling, as it is to an extent dependant upon the lifestyle of the inhabitants to carry out that recycling or at least segregation of materials. However, the dwelling should provide facilities for the recycling of a benchmarked proportion of the total domestic waste; this might include the provision of space for the separation and storage of different categories of waste or composting facilities.[18] If the project is of a sufficient scale, then proposals could be made for the private collection and recycling of separated waste, which would reduce the reliance

---

[15] DETR website, 9 March 2000: www.planning.detr.gov.uk/ppg3/.htm
[16] Kollhoff, Hans, 'Urban Building Versus Housing,' *Lotus*, Number 66
[17] Department of the Environment. 'Authoritative Municipal Waste Statistics Released', press release, 9 June 1997.
[18] Prior, Josephine J. and Paul B. Bartlett. *Environmental Standard – Homes for a Greener World*, London: Construction Research Communications Limited, 1995.

on inhabitants or local authorities.[19] Therefore this criterion will be based upon a percentage of the weekly production of domestic waste that should be recycled.

2.12 Ecological significance of the site

Whilst it has been acknowledged above that land is a natural resource, the value of that resource can vary depending upon a number of factors, including the ecological significance of the land. The criterion was included in the Building Research Establishment's *Environmental Standard* to discourage building upon ecologically valuable sites.[20] The criterion has also been establish through contemporary influences, such as the Government's ambition that 60 percent of the 3.8 million new dwellings required by 2021 to be built upon brownfield, or previously developed, land, and the millennium community competitions both of which were sited upon contaminated brownfield land.

The re-use of previously developed land will assist in reducing or arresting the destruction of natural habitat and the biodiversity it supports. However, it should not be assumed that just because land is brownfield it would have a low ecological value; if it has been derelict for a long period of time it may have been colonised by wildlife.

2.13 Ecological weight: embodied energy

Embodied energy is defined as the energy used in the production and transportation of the materials from which the dwelling is constructed. This would be consumed in the extraction of raw materials, the processing of these into building materials or components, and transportation at all stages up to delivery on site.[21] Embodied energy is typically quantified in terms of energy per unit mass of the material. The Ecological Weight is conceived as a measure of the total quantity of embodied energy that is used to produce the materials from which the dwelling is constructed. Although an established concept *Envest*, which is dedicated to office buildings, is the only environmental assessment method in the United Kingdom to quantify embodied energy.

---

[19] This is the scenario that is being developed for the reduction of domestic waste disposal by 50 percent at the Millennium Community in Allerton Bywater.
[20] Prior, Josephine J. and Paul B. Bartlett. Op. Cit.
[21] CIB Task Group 8. *Buildings and the Environment – Proceedings of the First International Conference*, at the Building Research Establishment, May 1994.

2.14 Ecological weight: embodied CO_2 emissions

As the embodied energy demands of material production are virtually exclusively fulfilled through the burning of fossil fuels, there will be a consequent CO_2 emission from their consumption; this is what is understood as the embodied CO_2 emissions.[22] It is a value that will be dependant not only upon the level of energy consumption, but also on the fuel types used as different fuels produce different quantities of CO_2 for the same amount of energy produced. This will therefore serve as a complimentary value to that of the embodied energy, ensuring that the materials used, whilst reducing the quantity of energy embodied in the dwelling, do not lead to increased levels of CO_2 emission.

2.15 Energy consumption: construction processes

This criterion will be an assessment of the energy used in the on site processes in the construction of the dwelling, as the embodied energy only takes account of the energy consumed up to the site gates. As with the criterion of CO_2 Emissions during Construction and Deconstruction, it was proposed in the *Environmental Standard* as an issue potentially to be included in future versions of the assessment, but is not included in *EcoHomes*, its subsequent revision.

2.16 Energy consumption: inhabitation

In a lifecycle analysis of the energy consumption of a dwelling, by far the highest proportion is consumed during the period in which the dwelling is inhabited.[23] Therefore a critical factor in the overall performance of the dwelling will be a measure of the quantity of energy that is consumed by the dwelling during its occupation. The total value will be made up from a number of contributing sources of consumption, although primarily these will be space heating, water heating, lights and appliances, cooking and pumps and fans.[24] Evidently the potential influence that a designer can have over these different sources will vary; for example consumption from appliances may be largely or wholly dependent upon the occupants of the dwelling, and therefore beyond the scope of the designer. There will also be indirect influences from other criteria, such as the thermal performance of the fabric and

---

[22] CIB Task Group 8, Ibid.; and Butler, David and Nigel Howard. 'From the cradle to the Grave', *Building Services*, November 1992.

[23] Typically between 85 and 90 percent of the lifecycle total.

[24] BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, London: HMSO, October 1998. These are the criteria used within *GIR 53* to breakdown the energy consumption of dwellings.

the air tightness of the structure, both of which will have a consequential effect upon the space heating consumption.

2.17 Energy generation: inhabitation

This criterion will assess the contribution made to the energy consumption of the dwelling, during its period of occupancy, that is generated from renewable, non-polluting sources of energy that are a part of the dwelling. Such sources could include photovoltaic panels or wind turbines. The only assessment of the performance of dwellings that includes energy generation through renewable sources is the SAP assessment, which only measures the contribution of solar water heaters to the water heating demand.[25]

2.18 Green space

The provision of green space in conjunction with the development of buildings was perceived as valuable for a number of reasons. Firstly, to provide spatial counterpoint, particularly in the context of increasing density; net density does not include the provision of strategic open space. Secondly, it will provide potential habitat for wildlife, and can therefore be considered in conjunction to the criterion of Ecological Significance of the Site. Thirdly, plant life assimilates CO_2 and therefore green space can assist in offsetting emissions arising as a consequence of embodied and inhabitation energy consumption.

The criterion will assess the provision of an area of green space in proportion to the scale on the building proposed. The type of space could range from a number of individual private gardens to a semi-private communal area to a public open space. It is a criterion that has been evolved through the research and does not, as far as has been possible to ascertain, have a precedent in other assessments.

2.19 Lifecycle cost

In the past costs incurred by buildings has been all but exclusively been quantified in terms of the initial construction cost, particularly in the case of dwellings were the client constructing the dwelling is not the long term occupier and therefore not responsible for maintenance costs. The Construction Task Force and the Construction Best Practice Programme have both identified construction cost for benchmarked reduction; however

---

[25] Department of the Environment, Transport and the Regions. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, London: Construction Research Communications Limited, 1998.

attention has also begun to be given to lifecycle costs. This is a measure of the cost of the dwelling throughout its lifecycle. It therefore includes the initial construction costs and then running costs, such as energy and water bills, throughout the life span of the building. There is an increased focus on the issue of lifecycle costs, not least through the temporal shift from construction to lifecycle cost reductions by the Construction Task Force and Movement for Innovation,[26] and in the increasing drive of sustainability. The focus on lifecycle, rather than merely construction, costs has advantages when studying the benefit of improved efficiency, where the benefit a higher capital cost can be justified through long-term savings in reduced running costs.

2.20 Nitrogen oxide emissions from gas boilers

Oxides of nitrogen (NO_X) are produced as a result of the burning of fossil fuels. Through combination with water in the atmosphere they produce nitric acids, and are thereby associated with the production of acid rain. Different fossil fuels produce different levels of NO_X dependant upon the nitrogen content, however the level produced is also dependent upon the burning temperature and the efficiency of the appliance. Therefore different boilers can produce different levels of NO_X emissions, hence the inclusion of this criterion.

This criterion was derived from the *Environmental Standard*, in which 'Boilers with reduced emissions of oxides of nitrogen' is proposed as an issue to be considered in future versions.[27] It was integrated into the EcoHomes assessment, the revised edition of the *Standard*, published during the research in May 2000.

2.21 Other ecological impacts of materials

The energy consumed in the extraction, production and transportation, and the consequent CO_2 emissions, will not be the only ecological impacts of the materials from which the dwelling is constructed. This criterion was proposed in the *Environmental Standard* as a potential issue to be considered in future revisions, and has been integrated, to some degree, in *EcoHomes*. Other environmental consequences of materials include: spoliation

---

[26] The Movement for Innovation briefly altered the benchmarked reduction target from construction to lifecycle cost, and then subsequently revised it back to construction cost. The Construction Task Force. *Rethinking Construction*, London: HMSO, July 1998; and, Movement for Innovation website, 30 June 1999: www.m4i.org.uk

[27] Prior, Josephine J. and Paul B. Bartlett. Op. Cit.; confidential draft proposals for the revision to the 1995 *Environmental Standard*, September 1999; Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.

of the natural environment during extraction, depletion of natural resources, and the release of pollutants.

2.22 Other greenhouse gas emissions

Whilst CO_2 is the most significant gas that contributes to the greenhouse effect, others also have an impact; these are: methane, chlorofluorocarbons and hydrochlorofluorocarbons, tropospheric ozone and nitrous oxide.[28] The emission of a quantity of these can arise from the processes associated with the construction or inhabitation of a dwelling, such as methane from landfill waste or tropospheric ozone created through the burning of fossil fuels.

One of the reasons that CO_2 is the most significant greenhouse gas is the quantity in which it is created. In terms of relative effectiveness of contribution to the greenhouse effect, measured per kilogram, these others can be many times more destructive.[29] Therefore, if the emission of CO_2 is cut significantly, then the relative contribution of these other gases to the greenhouse effect will increase. The criterion attempts to assess both the sources of these gases and the quantity of gas emitted.

2.23 Pollution: energy consumption during inhabitation

As with CO_2 emissions, the quantities of pollution emission created by the burning of fossil fuels, such as carbon monoxide, particulate matter and sulphur dioxide, will vary depending upon the type of fuel.[30] This criterion is intended to assess the level of these pollution emissions, in terms of the overall level of energy consumption and the balance of fuel types that are used to fulfil the energy consumption of the dwelling during inhabitation; this aims to ensure that types are not used that cause excessive levels of pollution when alternatives are available. Rather than assessing the absolute level of emission, this value will be relative, assessed in terms of the quantity of pollution emitted per kilowatt hour of the overall energy consumed, so that it is independent of the overall level of energy consumption. This is a criterion that has been developed during the research, and does not have precedent in other environmental assessments.

---

[28] Henderson, G. and L. D. Shorrock. Greenhouse Gas Emissions and Buildings in the United Kingdom', *IP2/90*, Building Research Establishment, April 1990.
[29] Rodhe, Henning. 'A Comparison of the Contribution of Various Gases to the Greenhouse Effect', *Science*, 8 June 1990.
[30] Howard, Nigel, Suzy Edwards and Jane Anderson. *BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings*, London: Construction Research Communications Ltd., 1999.

2.24 Procurement strategy

The procurement strategy defines the methods or processes through which the 'urban house in paradise' is realised. In *Rethinking Construction* principles are put forward for alternative procurement strategies, as oppose to competitive tendering, to produce best value and innovation in the construction industry, and with specific reference to housing.[31] The principal criticisms of competitive tendering are of its focus towards lowest initial price, and its lack of ability to differentiate between lowest price and *best value*; competitive tendering is perceived as conducive to the fragmentation and adversarial nature of the United Kingdom construction industry. The criterion considers more innovative ways in which to procure the 'urban house in paradise', with reference to initiatives such as the millennium community competitions, and with particular reference to the way in which it is defined, as a matrix of benchmarks.

2.25 Quality of internal environment: indoor pollution

The Canadian Residential Energy Efficiency Database makes recommendations on the air quality of the internal environment.[32] The *Environmental Standard* included a mandatory credit for 'hazardous materials' for the purpose of eliminating possible health risks and the unnecessary use of wood preservatives; it covered four materials: formaldehyde emissions, wood preservatives, asbestos and paints with added lead.[33] In dwellings with very low air leakage the potential problems of indoor air pollution could be exacerbated. Therefore there is justifiable cause to propose more demanding standards for high performance dwellings than might otherwise be considered sufficient. In terms of the 'urban house in paradise' the criterion considers the use of potential sources of indoor pollution through the use of materials that may emit harmful substances, rather than achieving a specific level of air quality based upon post-completion testing.

2.26 Quality of internal environment: daylight

Most people invariably prefer natural as opposed to artificial light. Increasing the quantity of daylight in the dwelling will reduce the need for artificial light, with a consequent reduction in energy consumption. However excessive window size would lead to both excessive heat loss, as windows are not as thermally efficient as walls, and excessive solar heat gain in

---

[31] The Construction Task Force. *Rethinking Construction*, London: HMSO, 1998.
[32] Residential Energy Efficiency Database website, 21 July 1999: www.its-canada.com/reed/iaq/no.htm
[33] Prior, Josephine. J., Paul B. Bartlett. Op. Cit.

summer months, to the detriment of the comfort of the inhabitants. Therefore it is important to relate the area of window openings to the energy consumption criterion, both through losses and gains. Daylight was included in the *Environmental Standard*, and its subsequent re-issue, requiring that dwellings meet the relevant British Standard. The criterion of the 'urban house in paradise' will assess the average daylight factor the habitable rooms within the dwelling.

2.27 Quality of internal environment: ventilation and air tightness

The quantity of energy required for space heating is dependent upon the heat loss from the dwelling; there are two principle sources of heat loss: thermal heat loss through the fabric, which is discussed below, and the infiltration of external cold air. Collectively this criterion considers the two sources of external air to the interior of the dwelling, ventilation and air tightness.

Ventilation considers the controlled rate of fresh air that is provided to the interior of the dwelling. A sufficient quantity is required to replace stale air inside the dwelling and therefore to maintain a comfortable, healthy internal environment; however, an excessive level will result in unnecessary heat loss. There are two forms of ventilation to consider, passive, or natural, and mechanical. The SAP assessment of the energy efficiency of dwellings includes an approximate evaluation of the heat loss from both natural and mechanical ventilation.[34]

Structural infiltration is the uncontrolled passage of external air into a building through the fabric of its envelope. The air tightness of the fabric envelope has been identified as one of the largest factors contributing to heat loss from dwellings.[35] *BREEAM/New Homes*, the previous issue of the *Environmental Standard*, contained a value for air tightness; however it was omitted from the next two re-issues. As a criterion of the 'urban house in paradise' air tightness also contemporary relevance; the proposed revision to the Building Regulations in England and Wales, due to come into effect during 2001, include potential air tightness

---

[34] Department of the Environment, Transport and the Regions. Op. Cit.

[35] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998; and BRECSU. 'Review of Ultra-Low-Energy Homes - Ten UK Profiles in Detail,' *General Information Report 39*, London: HMSO, March 1996.

levels.[36] The criterion considers the air tightness of the fabric through the rate of air loss that leaks out of the dwelling when the interior is pressurised.

2.28 Recycling of construction waste

Waste arising from the construction and demolition industry amounts to 7 percent of the total annual waste arising in the United Kingdom.[37] There is a proportion of the waste from construction sites that is unavoidable, sometimes referred to as the 'natural' waste, and therefore it is not technically feasible to prevent all construction waste. However research and empirical studies suggest that the quantity can be substantially reduced from current levels.[38] Of the amount of waste that cannot be eradicated, a high proportion can be recycled; just as for recycling of domestic waste, increasing the proportion that is recycled would reduce the volume sent to landfill, as well as the extraction of raw materials that could otherwise be provided by material from recycled sources. The criterion will consider the amount of waste arising as a consequence of the construction of the dwelling.

2.29 Recyclability of building: adaptability

Adaptability, as a criterion, is a measure of the ability of a dwelling to respond to changing needs over time. This emerged as a criterion to be included in the assessment tool during Drawn Study Two, which considered, among other issues, the potential adaptability of an urban building. It is also included within the GB Tool assessment method, an experimental tool currently under development,[39] and within *EcoHomes*, in which it is highlighted as a criterion that can be considered for inclusion over and above those in the assessment but which is not included in the evaluation itself.

2.30 and **2.31** Space standards: area and volume

This is a measure of the quantity of internal space within a dwelling, both in terms of the total net internal floor area, and the volume of space enclosed by the floor, walls, and ceiling or roof, in relation to the number of inhabitants that dwelling is design to accommodate. It is

---

[36] Department of the Environment, Transport and the Regions. *The Building Act 1994 – Building Regulations - Proposals for Amending the Energy Efficiency Provisions – A Consultation Paper Issued by Building Regulations Division*, London: HMSO, June 2000.
[37] Madden, Pauline. *Sustainable Waste Management*, unpublished BSc Construction Management thesis, Liverpool John Moores University, 1997.
[38] Madden, Pauline. Op. Cit.; and Skoyles E. R. and John R. Skoyles. *Waste Prevention on Site*, London: Mitchell, 1987.
[39] Cole, Raymond J. and Nils K. Larsson. 'GBC '98 and GB Tool: Background', *Building Research & Information*, Volume 27 Number 4/5, 1999.

conceived as a minimum standard, and not to propose that larger space standards should be discouraged.

The issue of space standards was most notably highlighted by Parker Morris in respect to social housing.[40] As a criterion to be included in the evaluation of the performance of a dwelling, this emerged from the work undertaken in Drawn Study 4, Allerton Bywater: The Scale of the Dwelling. The decision was taken to use the benchmarked construction cost savings to provide a larger dwelling for the same sale cost. Both area and volume were considered as affecting the space standard, the latter particularly so as space is perceived as a three dimensional environment. In addition, increasing the volume of the dwelling lead to improved air circulation and daylight penetration. To a lesser extent, the criterion is considered in the Housing Corporations assessment Housing Quality Indicators.[41]

2.32 Thermal performance

The thermal performance of the dwelling is a measure of how well the fabric of its envelope resists the passage of heat from inside to outside. It can, therefore, be a significant factor affecting the overall energy consumption of the dwelling in a northern European context. Within England and Wales, the Building Regulations ensure a mandatory standard of thermal performance for new dwellings, either for the individual elements or as an overall value for the envelope.[42] Research has been conducted into potential advances in the standard of the Regulations, particularly in the context of the much higher standards that exist in other countries, notably Scandinavia.[43] Therefore it is an obvious criterion to be included within a performance matrix of the 'urban house in paradise'.

The standard unit of measurement for the thermal performance is the U-value. This is a quantification of the rate of flow of heat, per unit area, from the warm side of the element to the cold side, and is mostly dependant upon the thickness of the element's component materials, and their respective thermal conductivity; the surface resistances of the element will also have a contributory effect.

---

[40] Walentowicz, Paul. *Housing Standards after the Act - A Survey of Space and Design Standards on Housing Association Projects in 1989/90*, London: National Federation of Housing Associations, 1992.
[41] Department of the Environment, Transport and the Regions website, 22 August 2000: www.detr.gov.uk/housing/information/hqi/index.htm
[42] Department of the Environment and the Welsh Office. *Approved Document L*, HMSO, 1995.
[43] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.

2.33 Use of reused or recycled materials

In the stocks and flows analysis of the lifecycle of a dwelling, used in chapter 3.0 in volume 1 to identify the criteria considered here, the principle cyclic as opposed to linear element was the reuse or recycling of materials. This could occur at both the construction stage of the dwelling's lifecycle, recycling materials from other buildings to construct the 'urban house in paradise', or at the demolition stage, recycling or reusing materials to create another building. Maximising the use of materials from recycled sources will minimise the depletion of primary resources. Partial recognition is given by the *Environmental Standard* for the use of demolition waste, recycled aggregates in concrete and recycled materials in masonry construction. If the strong linearity in the lifecycle of the dwelling is to become increasingly cyclic, then significant attention will need to be made to the lifecycle of the materials from which the dwelling is constructed.

2.34 Use of renewable raw materials

In situations where the use of reused or recycled materials is not viable, then primary raw materials will have to be used. In a context of the continual depletion of the earth's resources by unsustainable development, it is important that the matrix of the 'urban house in paradise' ensures that where the use of primary raw materials is necessary, they are from a renewable source. The 'urban house in paradise' will, therefore, not contribute to the further exploitation of the earth's finite natural resources and can be considered sustainable, at least under the Brundtland definition.[44]

2.35 Utilisation of local resources

As has been discussed within the thesis, sustainability extends beyond the boundaries of just ecology; it also has social and economic dimensions. The utilisation of local resources in the 'urban house in paradise' is a criterion that will reflect this. Transportation can account for a significant proportion of the total embodied energy of the dwelling; therefore using local materials will help reduce overall embodied energy content, and therefore emission arising from transport also. However, resources go beyond only the material. Whilst using local materials will aid the local economy, the utilisation of human resources will also benefit both social and economic sustainability. Therefore the utilisation of local resources, in terms of both materials and personnel, can benefit the social and economic sustainability of the local region, in addition to the local and global sustainability of the dwelling.

However, this criterion should be considered in the context of others. For example, whilst the use of local materials might initially seem advantageous, there may be more serious ecological disadvantages that outweigh any benefits if, say, the processes of extracting the local materials are particularly energy intensive, or have other serious ecological impacts.

2.36 Water consumption during construction

One of the ways in which the construction period of the dwelling could be reduced is the minimising of wet trades. Increasing the use of dry construction methods will have the dual advantage of both potentially increasing the rate of construction and reducing the quantity of water consumed on site.

Although commonly considered to be a limitless supply, water is a natural resource; its production, provision and disposal consumes energy, and therefore fossil fuels, resulting in resource depletion, CO_2 emission and pollution. Its inclusion as a criterion emerged during the development of Drawn Study Five, in considering how to increase the rate of construction on site. Within the context of the 'urban house in paradise' the criterion will evaluate the quantity of water consumed in the construction of the dwelling.

2.37 Water consumption: inhabitation

The mean level of domestic water consumption in the United Kingdom is 9.6 billion litres each day; this is predicted to increase by between 10 and 20 percent in England and Wales, without accounting for the effects of climate change.[45] The potential impacts of climate change include reduced supply and availability of water, in particular in the south and east.[46] As identified above, water is a natural resource, the purification, supply and disposal of which consumes energy and therefore causes pollution.

A feature-orientated assessment of water consumption was included within the *Environmental Standard*, awarding credit for the inclusion of low consumption appliances, rather than basing the evaluation on the total predicted level of consumption. The Canadian

[44] World Commission on Environment and Development. *Our Common Future (The Brundtland Report)*, Oxford: Oxford University Press, 1987, p. 43.
[45] Roaf, Dr Susan and Dr Peter Spillett, in Roaf, Dr Susan and Vivien Walker (eds). *21AD : Water*, Oxford: Oxford Brookes University, 1997.

Residential Energy Efficiency Database also highlighted the issue of water consumption during the period of occupation. The Green Builder Programme, developed in the United States of America evaluates the building in terms of both its internal and external water consumption.

The criterion will evaluate the quantity of water consumed by the inhabitants whilst undertaking the rituals of dwelling. It will also consider the potential ways in which that consumption can be minimised, and through this analysis propose reduction targets. Methods of water harvesting will be considered, such as rainwater collection and grey water recycling, as alternatives to the use of mains, potable water of drinking quality to supply all sources of consumption within the dwelling. The use of rainwater and grey water has many precedents, including the Vales autonomous dwelling in Southwell, refer to 5.2 in volume 1, and both of the millennium community competition winning submissions.

---

[46] Department of the Environment, Transport and the Regions. *Climate Change: The UK Programme*, London: HSMO, 1997.

Annexe 3

Benchmark Analysis of the Criteria

Annexe 3.0 Benchmark Analysis of the Criteria

This annexe contains the analysis undertaken to establish benchmark values for each of the criteria that define the 'urban house in paradise', which were proposed collectively in chapter 4.0, Benchmarking the 'Urban House in Paradise'. The text that precedes each value provides a description of the foundation that has been used to derive each respective value. For example, this might be the increase in performance that is theoretically possible over the current standards of dwellings constructed in the United Kingdom, or that which has been demonstrated as achievable by European best practice, but has not disseminated into the construction industry in the United Kingdom.

Following this a methodology is proposed for assessing each of the criteria. This is to ensure that a like for like analysis can be undertaken when comparing the performance of a dwelling with the 'urban house in paradise' to maintain consistency between different appraisals. The methodology of assessment for the most significant criteria that are evaluated by the tool is developed substantially further; refer to Chapter 9.0, Design of the Tool, in volume 1.

In the conclusion, a benchmark value is proposed. Wherever possible, this is accompanied by values that demonstrate the performance of a 'typical' speculative dwelling built by a national house builder to the standards required by the current Building Regulations, a comparative dwelling that demonstrates best practice in a European context, and one of the Drawn Studies undertaken during the first stages of the research. The intention is to provide a context in which the increase in performance proposed by the benchmark can be seen. In terms of the 'typical' speculative dwelling, it also provides data for the prioritising of the criteria. This acts as a control, baseline value, from which to calculate the reduction in ecological impact achieved when moving from the standard of the 'typical' dwelling to that of the 'urban house in paradise'.

3.1 Carbon Dioxide Emissions: Inhabitation

The greenhouse effect, with its consequent impact of climate change, is considered as one of the greatest environmental effects that man has had upon the planet. The relationship between greenhouse gases, including CO_2, and global warming is well established, and was predicted in the first instance by the Swedish physicist and chemist Svante Arrhenius (1859-1927) in a paper published in 1896. In the late 1980s, the Intergovernmental Panel on Climate Change (IPCC) was established to determine the implications of the perceived changes in climate. The IPCC suggest that to stabilise our climate would require reductions of greenhouse gas emissions in the region of 60 percent worldwide.[1] It is estimated that the period available for achieving this target is approximately 50 to 60 years.[2]

At the 1992 Earth Summit 154 states signed the Framework Convention on Climate Change, which includes the demand that signatory states stabilise greenhouse gas concentrations, '... at levels preventing a dangerous human interaction with the climate.' It is considered that if current trends continue, levels of carbon dioxide (CO_2) concentrations are certain to be reached that will very dangerously interfere with global climate.[3] Parties to the United Nations Framework Convention on Climate Change (UNFCCC) held in Kyoto, during December 1995, adopted the Kyoto Protocol. This sets out targets for Europe to reduce its emissions of the six primary gases that cause climate change. This target is to cut emission by 8 percent below the levels of emission in 1990, by the period between 2008 and 2012. Evidently this is somewhat below the targets identified by the IPCC. The reduction of greenhouse gas emissions is, therefore, a part of the agenda of the 'urban house in paradise.'

The level of domestic CO_2 emission at present is approximately 157 million tonnes; the goal by the year 2010 is approximately 134 million tonnes.[4] Since the Kyoto Earth Summit, the Government in the United Kingdom committed itself to go beyond the demands of the Kyoto Protocol, setting the target of a 20 percent reduction of 1990 levels of domestic emissions by 2010.[5] This is somewhat below the IPCC target of 60 percent reductions. In a recent change to the Building Regulations, the Government set out to achieve a 25 percent

---

[1] Intergovernmental Panel on Climate Change. *The IPCC Scientific Assessment*, London: Cambridge University Press, 1996.
[2] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, Earthscan Publications Limited, 1998.
[3] Ibid.
[4] Department of the Environment, Transport and the Regions. *A Better Quality of Life - A Strategy for Sustainable Development for the UK*, London: HMSO, May 1999.
[5] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.

reduction in CO_2 emissions by proposing for the first time that the revised Part L of the Regulations, on energy efficiency, apply to the refurbishment of existing buildings when changes to windows and heating system are made.[6]

Approximately 50 percent of the CO_2 emissions in the United Kingdom can be attributed to energy use in buildings, and 60 percent of this, or 30 percent of the total, can be attributed to the dwelling stock.[7] In addition, CO_2 accounts for around 87 percent of the relative contribution of the anthropogenic greenhouse gas emissions in the United Kingdom.[8]

The current level of CO_2 emissions created by the typical product of the United Kingdom housing industry, during its period of inhabitation, is summarised in the following table, based on a three-bedroom semi-detached dwelling built to current Building Regulation standards. Through the analysis of space standards, from which it has been determined that the three-bedroom semi-detached dwelling has a mean floor area of 84.2 m^2, this can be translated into values of kgCO_2 per m^2. This information demonstrates the main contributors to emissions during the habitation period of the dwelling's lifecycle, and therefore can be used to target where the greatest reductions may be created.

Source	Carbon Dioxide Emission		
	kgCO_2	percent	kg CO_2.m^{-2}
Space heating	1,506	36	17.8
Hot water	864	20	10.3
Cooking	125	3	1.5
Pumps and fans	96	2	1.1
Lights and appliances	1,650	39	19.6
Total	**4,241**	**100**	**50.4**

Table of CO_2 emissions for typical three-bedroom dwelling built to current standards.[9]

The CO_2 emissions arising during the period of inhabitation are primarily due to energy

[6] 'Dioxide Emissions Given No Quarter', *Building Design*, 16 June 2000.
[7] Shorrock, L. D. *Future Energy Use and Carbon Dioxide Emissions for UK Housing: A Scenario*, Building Research Establishment, July 1994; and BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report Number 53*, HMSO, 1998.
[8] West, John, Carol Atkinson and Nigel Howard. 'Embodied Energy and Carbon Dioxide Emissions for Building Materials,' Paper presented at the CIB Task Group 8 conference on 'Environmental Assessment of Buildings,' 16-20 May 1994, at the Building Research Establishment.
[9] Department of the Environment, Transport and the Regions, *General Information Report Number 53*, London: HMSO, 1998.

generation, through the burning of fossil fuels to create the energy consumed within the dwelling either within the dwelling itself or at power stations. In the case of the latter there are also upstream factors to be accounted for, such as the energy consumed in the extraction of fossil fuels, and the inefficiencies of generation and distribution. Furthermore, different fuels have different levels of emission, or emission factors, for equal amounts of energy provision. In addition to this are the emissions created by energy consumption during the extraction, processing, transport, erection, deconstruction and disposal or recycling of the materials used during construction, however, these are considered under the criterion of Ecological Weight: Embodied CO_2 Emissions, refer to Annexe 3.14. The generation of the energy consumed through the provision and disposal of water for a family of four releases approximately 200 kg CO_2 per annum.[10] Because of these interrelated factors, CO_2 emissions are an excellent example of a criterion and benchmark value that are dependent upon the consequential effects of other criteria.

Research published by the Building Research Establishment has studied the level of energy use, and consequent CO_2 emissions, from dwellings in the United Kingdom, and potential reductions that are achievable.[11] Two proposals for reductions were made: the first was from cost effective energy efficiency improvements to the 1987 housing stock, i.e. those with an adequate payback period; and secondly was the energy consumption and CO_2 emission reductions arising from the technically feasible improvements to the housing stock. The CO_2 emissions after cost effective measures were taken was predicted as a 25 percent reduction of the 1987 emission levels attributable to dwellings (173MtCO_2), and the emissions after technically feasible measures were taken was predicted to be 35 percent.[12] However, it must be born in mind that these improvements covered all of the housing stock, rather than just improving new build standards. As improvements to older, more inefficient housing stock will have a more significant impact in increased efficiency *pro rata*, caution should be exercised in interpreting these figures into benchmarks.

Research at the Building Research Establishment also made predictions of how emissions will change over time. It is suggested that, under current trends of growth and improvements in comfort levels, such as increased use of central heating, CO_2 emissions arising from dwellings will, after the year 2000, rise at a rate below 1 percent per annum, from a level of approximately 162 MtCO_2. Dividing this by the total number of dwellings equates to 7,398 kgCO_2 per dwelling. If this is the case, then the growth in CO_2 emissions approximately

---

[10] Shouler, M. C., J. C. Griggs and J. Hall. *Water Conservation*, Garston: Building Research Establishment, November 1998.
[11] Shorrock, L. D. and G. Henderson. *Energy Use in Buildings and Carbon Dioxide Emissions*, Garston: Building Research Establishment, 1990.

follows the prediction made for the increases in consumption and emission arising from household growth made by the thesis.

This scenario was subsequently updated[13] and revealed a drop in emissions arising from dwellings; this was primarily due to the use of updated electricity emission factors of the 1995 publication 'Energy Projections for the United Kingdom' *Energy Paper 65*.[14] The new level proposed was approximately 145 $MtCO_2$. Accompanying this updated scenario, which was again based on current trends, was one based upon increased uptakes in energy efficiency measures, such as insulation standards, glazing standards and water and space heating efficiency. The rate of adoption of the efficiency scenario was based on the fastest uptake rates that had been observed being sustained until reaching a saturation level, at which point all dwellings, or all dwellings to which the measures were appropriate, had adopted the measures. The reduction in CO_2 emissions arising from the scenario of increased efficiency standards was 13 percent of the emissions predicted by the current trend scenario by the year 2020. In 2016, at which point it is possible to predict the total number of household in the United Kingdom, the reduction was approximately 12 percent, and the new emission figure was 123.3 $MtCO_2$. This translates to a figure of 4,689 $kgCO_2$ per dwelling. Of course, this also relates to the upgrading of existing housing stock, most of which is at present highly inefficient. The majority of the dwellings in the United Kingdom today were built before thermal insulation requirement was integrated into the Building Regulations. The efficiency scenario of this research serves to bring the level of CO_2 emission arising per dwelling to just over 10 percent that of a dwelling built to current Building Regulation standards. Therefore, any significant reduction in the overall CO_2 emissions will demand that new dwellings produce greatly reduced levels of CO_2.

The *Environmental Standard* assessment model attributed a credit rating in terms of the level of CO_2 emission produced by a dwelling due to energy consumption, in terms of the period of inhabitation, not including construction or demolition. These figures were based on floor area, and given in three ranges of total floor area of the dwelling. These figures can be interpreted as an initial benchmark, of what is considered as a relatively high standard in comparison to conventional practice, to be refined by further primary and secondary studies.

---

[12] Ibid., p. 50.

[13] Shorrock, L. D. and J. E. Dunster. *Energy Use and Carbon Dioxide Emissions for UK Housing: Two Possible Scenarios*, Garston: Building Research Establishment, May 1997.

One credit is mandatory to achieve the award of the *Environmental Standard*, it require an emission in the region of:

Floor area (m^2)	CO_2 production ($kgCO_2.m^{-2}.a^{-1}$)
<50	31
50 to 100	30
>100	29

A second credit can be obtained by achieving the following standard:[15]

Floor area (m^2)	CO_2 production ($kgCO_2.m^{-2}.a^{-1}$)
<50	21
50 to 100	19
>100	17

The reduction in CO_2 emission between these two standards, i.e. typical practice and best practice, is approximately at least 31.2 $kgCO_2.m^{-2}.a^{-1}$, or 62 percent.

EcoHomes, the subsequent revision of the *Environmental Standard*, published during this research, extended and advanced the reduction in emissions required to achieve the award of a credit; the greater the reduction that is made, the higher the score awarded. The maximum level of emissions that would achieve recognition was reduced to 50 $kgCO_2.m^{-2}.a^{-1}$; this drops in increments of 5 $kgCO_2.m^{-2}.a^{-1}$ to zero, for which the maximum score is given.[16]

In the recent publication 'Building A Sustainable Future - Homes for an Autonomous Community,'[17], proposals were considered for the viability of the zero CO_2 dwelling, which would create no net emissions of CO_2 on an annual basis. In this case any contribution to CO_2 emissions arising from the consumption of any non-renewable energy sources must be compensated for through exporting sufficient renewable energy to compensate for the emissions associated with the imported energy. A dwelling that achieves these parameters

---

[14] Department of Trade and Industry. 'Energy Projections for the United Kingdom' *Energy Paper 65*, London: HMSO, 1995.
[15] Prior, Josephine. J., Paul B. Bartlett. *Environmental Standard - Homes for a Greener World*, Garston: Building Research Establishment, 1995, p. 6.
[16] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.

would almost fulfil the *Factor Four* criterion of being a net exporter of energy.

General Information Report 53 proposes that a zero heating dwelling, utilising 40W mechanical ventilation with heat recovery, a 30 percent reduction in water use, and fitted with the most efficient lighting and appliances available on the market, would achieve a consequent CO_2 emission level of 2.5 tonnes per annum. Assuming a typical floor area of 84.2 m^2, determined through the analysis for the Space Standards benchmark, this can be translated as a benchmark of 29.7 $kgCO_2.m^{-2}.a^{-1}$.

To achieve the reductions of 60 percent put forward by the IPCC, to create a stabilisation in levels of atmospheric CO_2, will put significant demands on new housing. A 60 percent reduction from that of the typical dwelling built to current regulatory standards would equate to a benchmark of 20.16 $kgCO_2.m^{-2}.a^{-1}$.[18] However, because the thermal performance of the existing housing stock is so poor, the improvements in new dwellings will be required to be even higher, in order to counteract the effects of the existing, inefficient stock. However, there are precedents for such improvements in performance. The new Kronsberg Urban District is a large-scale housing project being constructed in Germany, in close proximity to the Hanover Expo 2000 site. It is proposed that the 6,000 dwellings, accommodating around 15,000 people, will reduce CO_2 emissions by 60 percent of that which might be expected from a typical German development of a comparable scale.[19]

The initial winning submission to the Greenwich Millennium Community Competition proposed a net benchmark of zero CO_2 emissions. The benchmark of an 80 percent reduction in energy consumption can be used to determine the gross CO_2 emission benchmark.[20] If the value of 50.4 $kgCO_2.m^{-2}.a^{-1}$ is taken as a typical mean value, then the gross emissions can be speculated as 10.1 $kgCO_2.m^{-2}.a^{-1}$. However, the net zero CO_2 emission has been eradicated from the current benchmark targets for the project, and the first phase of the dwellings are likely only to achieve a 65 percent reduction in energy consumption,[21] equating a CO_2 emission of 17.6 $kgCO_2.m^{-2}.a^{-1}$.

A comparative benchmark based upon best practice in northern Europe can be provided by Passiv Haus in Darmstadt, which also serves as the comparative in the Energy Consumption:

---

[17] Department of the Environment, Transport and the Regions. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report Number 53*, London: Construction Research Communications Limited, 1998.
[18] This is 40 percent of the 50.4 $kgCO_2.m^{-2}.a^{-1}$ determined in the table above.
[19] Hanover Online website, 14 December 1999: www.expo.hanover.de/english/tourist/weltauss/welt_han/exponate/eoko_kro.htm
[20] Baldock, Hannah. 'Can Prescott Save the Village?', *Building*, 8 October 1999.
[21] Spring, Martin. 'Prescott's Village Rises Slowly From the Mud', *Building*, 15 December 2000.

Inhabitation benchmark. The energy use for the dwelling was measured as a total of 32 kWh.$m^{-2}.a^{-1}$, of which 10 was attributed to space heating which was provided by a gas-fired condensing boiler; gas was also used as the fuel for cooking.[22] The emission factors for the respective fuel types can be used to approximate the consequential gross CO_2 emissions form the dwelling; the value will approximate because the electricity will be based upon the emission factor for electricity in the United Kingdom, which may differ from that in Germany. This equates to a benchmark of 15.9 kgCO_2.$m^{-2}.a^{-1}$.

The level of CO_2 produced during the period of inhabitation will be dependent upon two factors, the first is the level of fuel consumed to serve the dwelling, and the second is the type of fuel consumed. The first will be affected by the efficiency of the dwelling. The second factor arises because different fuel sources produce different levels of CO_2 emission; this is demonstrated in the following table. It is necessary, therefore, to define not only the level of energy consumption for the dwelling, but in addition the type of fuel consumed in order to determine the CO_2 emission. The table below shows the different emission factors for a number of fuels commonly used for fulfilling the energy demands of dwellings.

Fuel Type	CO_2 emission (kg CO_2 per kWh delivered)
Electricity	0.75
Coal	0.31
Fuel oil	0.28
Gas	0.21

CO_2 emission by fuel type delivered[23]

The benchmark level of CO_2 emission of the 'urban house in paradise' will, therefore, be informed by the benchmark of Energy Consumption: Inhabitation, which is given in the table below.

[22] BRECSU. 'Review of Ultra Low Energy Homes – A Series of UK and Overseas Profiles,' *General Information Report Number 38*, London: HMSO, February 1996.

Function	Energy consumption (kWh.m^{-2}.a^{-1})
Space heating	12
Hot water	included above
Pumps and Fans	3
Cooking	3
Lights and Appliances	7
Total	**25**

Energy Consumption: Inhabitation benchmark of the 'urban house in paradise'[24]

If, as benchmarked under the criterion of Energy Generation: Inhabitation, the assumption is made that 100 percent of the energy consumption of the dwelling is provided by renewable sources, then none of the energy consumption of the dwelling is provided by fossil fuels. If, however, that benchmark were not achieved then the CO_2 emission arising from the dwelling would be:

Function	CO_2 emission (kgCO_2.m^{-2}.a^{-1})		
	gas	electricity	Combined 'best case'
Space heating	2.52	9.0	2.52 (gas)
Hot water	included above	included above	included above
Pumps and Fans	-	2.25	2.25 (elec)
Cooking	0.65	2.25	0.65 (gas)
Lights and Apps	-	5.25	5.25 (elec)
Total			**10.7**

CO_2 Emissions as a consequence of Energy Consumption: Inhabitation benchmark

The distinction between CO_2 emissions before and after the contribution of renewable sources are accounted for, such as wind turbines or photovoltaic panels, is made by the

[23] Department of the Environment, Transport and the Regions. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, London: Construction Research Communications Limited, 1998.
[24] Refer to Annexe 3.16.

value of net and gross emissions. If a dwelling uses photovoltaic panels, then a method of storage will be necessary for periods when the panels do not generate the energy that is being consumed by the dwelling, such as at night or on overcast days. This could be in the form of batteries, but a common method is to use the mains national grid. During periods when there is an excess of energy, because the panels are generating more than the dwelling is consuming, the excess is supplied to the grid; during periods when demand exceeds the supply from the panels, the grid is used to supply the shortfall. If over a period of a year, for example, the consumption taken from the grid is less than or equal to the energy supplied to it, then the dwelling can be described as having zero net CO_2 emissions.[25] Also, if fuels other than electricity are used within the dwelling, such as gas for space and water heating, then the electricity generated by the dwelling will not create an exact balance; there will still have been the fossil fuel consumption of the gas. The value of gross emissions is based upon the quantity that would of occurred had there been no supply of renewable energy.

The concept of benchmarking the CO_2 emissions arising from the dwelling due to the energy consumed during inhabitation has particular relevance to the proposed revisions to the Building Regulations in England and Wales. In the consultation document, published in June 2000, it was suggested that from Stage 2, to be implemented one year after the initial amendments, the satisfactory operating performance be defined through performance targets of carbon emissions.[26] These targets could be based on either national benchmarks for each sector, the pervious year's performance of the building being assessed, or a combination of these two. No quantitative benchmarks have as yet been proposed.

Method of Assessment

As identified under the Energy Consumption: Inhabitation benchmark, the Standard Assessment Procedure of energy rating dwellings also provides a way of determining the overall CO_2 emission of that dwelling, based on the energy consumption level calculated. The disadvantages of using the SAP model to determine in level of energy consumption was discussed, due to its lack of consideration of energy use from lighting and appliances whilst including the gains from these sources; however, the Building Research Establishment's Domestic Energy Model provides a methodology for calculating the energy consumption form these sources. Also, research by the Environmental Change Unit at the

[25] This has precedent in a number of low-energy dwellings such as the Oxford Solar House and the Vales' Autonomous house in Southwell; refer to the case studies in chapter 5.0, volume 1.

University of Oxford can be used to determine the emissions from these sources.[27]

The calculation of the benchmark of CO_2 Emissions: Inhabitation will therefore be based upon the level of energy consumed by the dwelling. The quantity of energy consumed by each of the sources in the table above will qualified by the fuel that is used to supply the source. Standard emission factors, in terms of $kgCO_2.kWh^{-1}$ can then be used to convert this into the quantity of CO_2 emissions that would occur as a consequence of that energy consumption. This will give the gross CO_2 emissions. The net quantity of emissions can then be determined by deduction the reduction that is attributable to energy generated by the dwelling. For example, if the dwelling has photovoltaic panels, the equivalent emissions that would be created by using mains electricity to supply that energy can be deducted from the gross benchmark.

Conclusion: CO_2 from Energy Consumption

Therefore, assuming the best case scenario, where the fuel choice is made to maximise the reduction of CO_2 emissions, then the benchmark of the 'urban house in paradise can be summarised in the following table. However, this gross value can be cut further through using renewable sources of energy, to a net value of zero if renewably sourced electricity is used throughout the dwelling, but to benchmark this as a minimum would dictate the use of technology and there may be situations in which the matrix is used where such technologies are not appropriate for financial or other reasons. Therefore, as for all of the benchmarks, this value is a minimum performance standard that can be improved upon.

	CO_2 emission ($kgCO_2.m^{-2}.a^{-1}$)
Typical UK speculative dwelling	50.4
European comparative: Passive Haus	15.9
Drawn Study: 5	23.9
The 'urban house in paradise'	**10.7**

CO_2 Emission: Inhabitation benchmark for the 'urban house in paradise'

However, the emissions arising from the consumption of energy by heating, lighting and

[26] Department of the Environment, Transport and the Regions. *The Building Act 1994 – Building Regulations - Proposals for Amending the Energy Efficiency Provisions – A Consultation Paper Issued by Building Regulations Division*, London: HMSO, June 2000.
[27] Boardman, Brenda et al. DECADE: Domestic Equipment and Carbon Dioxide Emissions – Second Year Report, Oxford: University of Oxford, 1995.

appliances will not be the only contribution that the dwelling will make to its overall CO_2 output during the period of inhabitation. Because of this there will be links to other criteria within the matrix that have a consequent CO_2 emission, such as Water Consumption: Inhabitation and Green Space. This is another respect in which the matrix of the 'urban house in paradise' is different to existing environmental assessment models, and demonstrates the benefits of accounting for the interrelationship between criteria; it facilitates the creation of a much more realistic representation of the overall impact of the dwelling.

Emissions from water consumption benchmark:

Providing 600 litres of water each day for a family of four creates 200 kg of CO_2 per annum, created by the generation of 120 kWh of energy that is required to provide it, and 100 kWh per year consumed in treating the subsequent waste water.[28] For the 'urban house in paradise' the level of mains water consumption is benchmarked as 6.5 litres per person per day. Thus the energy consumed during the provision of that water will be 1.6 kWh, and the energy consumed during the treatment and disposal of the 61.9 litres of waste water will be 10.3 kWh. This total of 11.9 kWh per person per year equates to a CO_2 emission of 10.8 $kgCO_2$ per person per annum. This figure is unlikely to be included within the Department of the Environment, Transport and the Regions figures of CO_2 emissions given above, which focuses on emissions occurring from energy use within the dwelling, such as space and water heating. At a mean occupancy level of 2.4 people per dwelling,[29] this can be equated to a value for the dwelling of 25.9 $kgCO_2.a^{-1}$. This value needs to be converted into terms of $kgCO_2.m^{-2}.a^{-1}$, in order that it can be added to the value derived for emissions from energy consumption; from the Space Standards: Area analysis, the typical dwelling has a mean area of 59.8 m^2, and therefore, the emission level will be 0.4 $kgCO_2.m^{-2}.a^{-1}$.

Effect of the Green Space Benchmark:

As green space is an assimilator of CO_2, through the process of photosynthesis, the benchmarked provision of green space, both as a habitat and as a food provider, will contribute to the net reduction of CO_2 within the atmosphere.

---

[28] Shouler, M. C. and J. Hall. *Water Conservation*, Garston: Building Research Establishment, November 1998.
[29] Office for National Statistics. *Living in Britain - Results from the 1995 General Household Survey*, London: Government Statistical Service, 1995.

Research into the ecological footprint of fossil fuels has determined the most effective assimilators of CO_2 in terms of green space, which are forests, can sequester 1.8 tonnes of carbon per hectare.[30] This value can be used to determine the best case scenario for the potential level of annual CO_2 absorption by the green space benchmarked to be provided for each dwelling.

If we take a benchmark that a space 20 percent of the floor area of the dwelling will be provided for each new dwelling created, then for a typical occupancy of 2.4 people, this will be 20 percent of 59.8 m^2, or 11.96 m^2. From the relative atomic masses, 1 kgC is the equivalent of 3.67 $kgCO_2$. Therefore, the assimilative capacity of the green space will be 6.6 tonnes CO_2 annually per hectare. This can be converted to 0.66 $kgCO_2/m^2$/annum.

Total Value

Therefore the total value from each of these criteria will be:

$$\text{Total } CO_2 = x + y - z$$

where x = CO_2 emission from energy consumption
y = CO_2 emission from water consumption
z = CO_2 assimilation from green space

$$= 10.7 + 0.4 - 0.7$$

$$\mathbf{= 10.4\ kgCO_2.m^{-2}.a^{-1}}$$

This value will presume that all of the benchmarks are achieved.

[30] Wackernagel, M. and W. Rees. *Our Ecological Footprint*, New Society Publishers, 1996.

3.2 Carbon Dioxide Emissions: On Site Construction Process

The consumption of fossil fuels during the on-site processes of the construction of the 'urban house in paradise' will result in consequent carbon dioxide emission. As with the benchmark of CO_2 Emissions: Inhabitation, the magnitude of this value will be affected by two factors, the quantity of energy consumed by the construction processes and, as different fuel types produce different levels of emission per kWh consumed, the type of fuels used. Therefore, the value of CO_2 emission per unit of fuel consumed must reflect the processes of construction.

The benchmark value of the energy embodied in construction process of the typical speculative built dwelling was determined as 150 $kWh.m^{-2}$; this figure can be used to determine an approximate value of the carbon dioxide emissions arising as a consequence of the consumption of this energy. A mean value of an emission factor for a typical balance of fuel types used during the construction of a dwelling can be derived from Howard;[1] this equates to a value of 0.36 $kgCO_2.kWh^{-1}$. Therefore, an approximate value of the CO_2 emissions arising from the energy consumed during construction of the typical speculative built dwelling can be determined as 54.0 $kgCO_2.m^{-2}$.

The comparative dwelling of best practice in embodied energy achieved a benchmark estimated to be 250 $kWh.m^{-2}$. If 15 percent of this value were used in the construction of the dwelling on site, it would equate to a benchmark for Energy Consumption: On Site Construction Processes of 37.5 $kWh.m^{-2}$. This could be converted using Howard's constant to a CO_2 Emissions: On Site Construction Process benchmark of 13.5 $kgCO_2.m^{-2}$. However, it can be assumed with any degree of certainty that the ratio of energy consumed on site to the total embodied energy will apply to dwellings with a very low embodied energy. However, as the dwelling was built using very low mass construction methods, and probably timber-framed, it will very likely have used prefabrication, which will reduce the energy consumed on site. Also, it is unlikely that the dwelling would be achieve that value with any masonry construction, which is energy intensive. The value will be included in the table below, but should be treated with a degree of caution for the reasons highlighted above.

Drawn Study Five can also provide an approximate value of the CO_2 emissions arising as a consequence of construction processes. The value will be based upon the Ecological Weight: Embodied Energy benchmark, determined in 3.13. If the same assumptions are made for the example above, but this time for a high-mass dwelling, the consequent emissions can be calculated as 34.6 $kgCO_2.m^{-2}$.

The benchmark reduction of Energy Consumption: Construction Processes is a 50 percent reduction from that of the 'typical' dwelling, which equates to a benchmark value of 75 $kWh.m^{-2}$. Using the mean value of CO_2 emissions of the different fuel types used in construction, derived from Howard, gives a CO_2 emission benchmark for the 'urban house in paradise' of:

$$75 \times 0.36 \qquad = 27\ kgCO_2.m^{-2}$$

Methodology of Assessment

A breakdown of specific energy consumption rates by individual processes has not able to be determined. It is possible that this information does exist a the Building Research Establishment has undertaken a significant amount of research on the embodied energy of construction after materials have been delivered to site; however this information is retained on a confidential database within the Centre for Sustainable Construction.[2]

Therefore, the benchmark value will be based upon the ratio of the energy consumed by the construction processes on site to the total embodied energy of the dwelling, and converted into a value of CO_2 emissions using the constant of 0.36 $kgCO_2.kWh^{-1}$, derived through the literature review. Should it transpire that a more accurate methodology can be established, based on the actual fuel consumption by both type and quantity for different construction methods, this can supersede the approximation that the methodology outlined above will give.

Conclusion

Therefore, the proposed value of the benchmark of the CO_2 emission arising from the energy consumed during the construction of the 'urban house in paradise', in the context of the comparative standards can be summarised in the table overleaf.

---

[1] Howard, Nigel. 'Energy in Balance,' *Building Services*, May 1991.

	CO_2 emission ($kgCO_2.m^{-2}$)
Typical UK speculative dwelling	54
European comparative: Knightstone	13.5
Drawn Study: 5	34.6
The 'urban house in paradise'	**27**

CO_2 Emission: On Site Construction Processes benchmark for the 'urban house in paradise'

[2] Personal communication with Suzy Edwards of the Sustainable Construction Unit at the Building Research Establishment, 5 October 1999.

3.3 Carbon Intensity: Space and Water Heating

In research conducted on behalf of the Joseph Rowntree Foundation, into the potential future of the Building Regulations of England and Wales,[1] Lowe and Bell propose that in future versions of the Regulations, in addition to the Elemental and Target U-value calculations, a 'carbon intensity threshold' should be established for space and water heating systems. This is suggested as a potential alternative to a modified Energy Rating Method, in order to account for variation in the carbon intensity of domestic fuels.

The level of carbon emission arising from for space and water heating appliances is affected by the efficiency of the heating system and its control methods, and by the type of fuel being used, and also the thermal performance of the envelope. As the latter will be benchmarked elsewhere, under the criterion of Thermal Performance, this criterion will set out to establish the former parameters. The interrelated links in the tool can then create the linkage to the thermal performance.

The carbon intensity can be defined and quantified as the ratio of total carbon dioxide emissions from the heating system to the total useful heat output for space and water heating, over an annual cycle.[2] It is, therefore, a measure combining the efficiency of the performance of the heating system, taking account of the fuel type that is used; the latter point is significant because the carbon intensity, quantified in units of $kgCO_2.kWh^{-1}$, of different fuel types can vary significantly. For example, although an appliance may use a fuel type with a very low carbon intensity, if it is inefficient it may in practice produce more carbon dioxide per kilowatt hour than a highly efficient appliance running on a fuel with a high carbon intensity.

The proposed threshold values, by Lowe and Bell, are 0.28 $kg.kWh^{-1}$ in the year 2000, falling to 0.24 $kg.kWh^{-1}$ in 2005. These values would be achievable by, in the case of the former, a non-condensing gas system, and in the latter situation, by a condensing gas system. As 0.24 $kg.kWh^{-1}$ represents a best practice standard, it will be adopted as a benchmark for the 'urban house in paradise.'

The Carbon Intensity benchmark for a typical dwelling can be determined using the methodology provided by Bell. The calculation is based upon thermal efficiency of non-

[1] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.
[2] Personal communication from Robert Lowe, Leeds Metropolitan University, December 1999.

condensing boiler with permanent pilot light, derived from data in the SAP assessment.[3] The benchmark can be determined by dividing the carbon content of the delivered energy by the coefficient of performance, which is taken as 69 percent.

$$CI = Cd / \eta$$

$$0.21 / 0.69$$

$$\text{Carbon Intensity} = 0.30\ kg.kWh^{-1}$$

The Carbon Intensity of Drawn Study Two is calculated in the same manner, but assumes a coefficient of performance of 83 percent, which is provided by a condensing gas boiler with automatic ignition. This equates to a Carbon Intensity benchmark of 0.24 $kg.kWh^{-1}$.

It has not been possible to determine the coefficient of performance for a comparative of European best practice. As this is required to calculate the benchmark of carbon intensity the European comparative will have to be omitted in this case. The Passive Haus in Darmstadt used a condensing gas boiler for space heating,[4] and therefore the efficiency could be assumed. However, this would not provide a value other than that proposed by Lowe and Bell, and therefore would be of limited value.

Methodology of Assessment

The methodology used to assess the level of compliance with this benchmark will require manufacturer's data for appliances during their specification, as the carbon intensity benchmark is dependent upon the coefficient of performance, or efficiency, of the heating system or appliance. The carbon intensity can be estimated using the following equation:

$$CI = Cd / \eta$$

Where CI = carbon intensity benchmark ($kg.kWh^{-1}$)

Cd = carbon content of delivered energy, e.g. 0.21 $kgCO_2.kWh^{-1}$ for gas

η = coefficient of performance (%)

[3] Department of the Environment, Transport and the Regions. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, London: Construction Research Communications Limited, 1998.

[4] BRECSU. 'Review of Ultra Low Energy Homes – A Series of UK and Overseas Profiles,' *General Information Report Number 38*, London: HMSO, February 1996.

Conclusion

Therefore, the proposed benchmark for the criterion of Carbon Intensity: Space and Water Heating, seen in the context of the other comparative benchmarks of the typical speculative dwelling and Drawn Study Two: Glasgow – Scale of the Dwelling, is proposed in the table below:

	Carbon Intensity ($kg.kWh^{-1}$)
Typical UK speculative dwelling	0.30
European comparative:	-
Drawn Study: 2	0.24
The 'urban house in paradise'	**0.24**

Carbon Intensity benchmark for the 'urban house in paradise'

3.4 Construction Period

The aspirations of the Movement for Innovation (M^4I), the body charged with the task of interpreting recommendations made in the Construction Task Force's report into reality, in addition to benchmarking construction cost reductions also benchmark proposed reductions of the time taken to construct a project. Their aim is to achieve:

> ... through sustained improvements and innovation in product design and development, in project implementation, in partnering the supply chain and in production of components: 10 percent improvements each year in lifetime costs, construction time, productivity and profits.[1]

Just like the cost reduction targets of the M^4I, their construction time reduction targets are being implemented through the Construction Best Practice Programme's Key Performance Indicator (KPI) benchmarks.[2] The KPIs provide a measure of the performance of a project against industry average benchmarks; in terms of construction time, the objective of the benchmark is to measure the,

> Change in the normalised time to construct a project in 1998 compared with 1997, expressed as a percentage of the 1997 time.[3]

The methodology of assessing the benchmark of construction time reduction requires identifying a comparable project the construction of which commenced one year prior to the one that is to be benchmarked. For both projects the contract sum and contract period is determined; the contract sum of both are then normalised to account for variations in location, size, and changes in resource cost. Each contract period is then divided by the normalised contract sum to determine the Construction Time Factor for each project. The percentage change between the Construction Time Factor for the current and the previous year is then calculated, and the percentage change between the two is used, with a graph provided, to translate this percentage into a benchmark score.

The value of the KPIs for a specific project can then be compared with the average performance of the rest of the construction industry, either for all construction or for a

---

[1] Movement for Innovation website, 30 June 1999: www.m4i.org.uk.
[2] Refer to the Lifecycle and Construction Cost annex for a more detailed description of the Key Performance Indicators.
[3] Construction Best Practice Programme. *Key Performance Indicators 1998 - Project Delivery and Company Performance*, London: HMSO, 1999. The normalised time takes account of factors such as regional variation in tender costs, inflation, and differences in quality.
[4] Construction Best Practice Programme website, 1 May 2000: www. cbpp.org/themes/suscon

particular sector. The 1998 average KPIs for the construction time of new build housing were:

	Industry Average Performance
New build housing - Private	+ 5 percent
New build housing - Public	- 4 percent

These are clearly still a long way from the annual 10 percent reduction advocated by the Construction Taskforce and the M[4]I. The identified reduction in construction period is principally perceived as a source of reducing construction cost, although other benefits such as less noise, disruption and intrusion are highlighted that could improve the sustainability of the project.[4] The Building Research Establishment is currently conducting research into the effect of the transportation of site workers to and from site;[5] reducing the construction period would lessen impacts arising from this.

Of course, the KPI benchmarks are calculated post completion; if the matrix of criteria of the 'urban house in paradise' is to be used at the design stage then the performance against the benchmark of the matrix will have to be predicted. Therefore the benchmark will be a design target, and the success of the performance against the benchmark could only be fully evaluated after completion. This is where the close interrelationships fostered within the team will be beneficial, to make accurate predictions about the likely construction rate and construction cost of the dwelling.

The time taken to construct a typical dwelling built by a national house builder is taken as 12 weeks.[6] Therefore, the initial benchmark by the M[4]I would equate to a construction period of just less than 11 weeks per dwelling. It was envisaged by the construction consultant for Aire Design that the Aire 8100 dwelling, developed during Drawn Studies Four and Five, could be constructed at three times the typical rate of the national house builder, equating to a construction period per dwelling of 4 weeks.[7]

In the submission of its entry to the Millennium Community competition at Greenwich, the team led by Hunt Thompson Associates, later known as HTA, and Countryside Properties proposed that the rate of construction would be 25 percent quicker than normal. This represented a significantly higher target than the Construction Task Force's and Movement for Innovation's target of 10 percent. Subsequent to the change in architects, when HTA

---

[5] Personal communication with Suzy Edwards of the Sustainable Construction unit of the Building Research Establishment, 5 October 1999.

[6] Personal communication with Barratt Leeds, during the development of the Allerton Bywater Millennium Community competition entry.

Architects left the project and were replaced by Proctor Matthews Architects, further details of the construction and cost of the dwellings were released. Built from timber frame as prefabricated cassettes, the developer pledged that that it would build 100 dwellings every 72 weeks.[8] This represented an attempt to meet the goals put forward in the *Rethinking Construction*. This value could be equated to 0.72 weeks per dwelling, less than one week per dwelling.

The national house builder Wimpey Homes, the social landlord Guiness Trust and Britspace, who have developed the construction methodology it uses for McDonalds restaurants in housing, have created a prototype semi-detached unit of dwellings. Built from eight interlocking prefabricated modules, the dwelling initially appear to be the typical product of a national house builder, of a two-storey, two and three bedroom semi-detached unit in brick construction. However, the brick is a wafer thin applied finish to the panels. Although the technology is not being applied to wide-scale construction, and only exists as a single experimental prototype, it is a valid precedent. In terms of construction period, the panels took three weeks to manufacture, and were programmed as taking two weeks to construct on site. Therefore, the total construction period was 2.5 weeks per dwelling.[9]

In terms of European comparatives, where the use of prefabrication technology is much more established than in the United Kingdom, the German company Europahaus have produced a dwelling that can be erected in half a day.[10] Aimed to supply low-cost housing, steel framed, prefabricated elements are fully finished, including decoration, and are bolted together on site. The final internal finishing takes a further one and a half days, after which it is claimed that the inhabitants can occupy the dwelling.

The construction period of the Europahaus is very short, and could be dependent upon the use of a similar construction technology to achieve a comparable standard. This could be construed as influencing the design process. Therefore, the benchmark of the 'urban house in paradise' was determined by considering each of the best practice comparatives above, and a value that innovates upon the mean standard chosen. It is also one that reflects a factor four reduction of the typical dwelling produced by a national house builder, taken as a philosophical underpinning for the benchmarking process. The technologies identified above that are below the benchmark of the 'urban house in paradise' may provide insights into the ways in which the benchmark could be achieved.

---

[8] Booth, Robert. 'Prescott Sticks to His Guns Over Greenwich Targets', *Building Design*, 24 April 2000.
[9] Smit, Josephine. 'Max Factory', *Building Homes*, November 1999.
[10] Frairs, Marcus. 'New German Houses Built "In an Afternoon"', Building Design, 22 May 1998.

Methodology of Assessment

A consistent methodology will have to be adopted to quantify the period taken to construct a dwelling, which can apply to individual units, linked units and multi-storey apartments. It is proposed that this be weeks per dwelling. The design benchmark will be based upon the construction programme. If the dwelling is not an individual unit, then the time taken to complete the block, whether a terrace or multi-storey block, will be divided by the total number of units. A post-completion re-evaluation of the benchmark will determine if it has, in reality, been achieved.

Conclusion

Therefore, the proposed value of the benchmark of the Construction Period for the 'urban house in paradise', in the context of the comparative standards, is summarised in the table below.

	Construction Period (weeks.dw^{-1})
Typical UK speculative dwelling	12
European comparative: Europahaus	0.5
Drawn Study: 5	4
The 'urban house in paradise'	**3**

Construction Period benchmark for the 'urban house in paradise'

3.5 Contextual Significance of the Site

This criterion is of critical importance in terms of the retention of cultural heritage; architecture can be considered as a representation of man's presence through time, and buildings, including dwellings, are a part of the culture and spirit of an age. Scott writes that, "The history of civilisation thus leaves in architecture its truest ... record."[1] This issue if of particular relevance due to the predication of the thesis upon urban housing, where the contextual significance of the site is likely to be greater. Its aim is to ensure that due consideration is given to the surrounding buildings and urban grain in the development of the project's design.

The first aspect will be to consider the contextual significance of a specific site. This may be explicit through the site being located within or in close proximity to a conservation area, or in proximity to or containing listed buildings. However, the contextual significance may be more implicit. Therefore, a contextual analysis, an evaluation of the site and its surroundings, should be undertaken prior to the design of the building. This should also include a historical analysis of the site, using Ordinance Survey plans of the site, to ascertain if any contextually significant elements or features have been erased.

The response to the contextual significance could be made in a number of ways; the thesis maintains that creative design is not a monistic process. For example, the influence of a significant building on an adjacent site could impact upon the proportion, hierarchy or materiality of the new building. This influence could be more a matter of space, arrangement and scale, rather than sympathetic stylistic façadism; the Jewish Extension to the Berlin Museum by the Polish architect Daniel Libeskind (1946-) is exemplary as an innovatory response to the context of the site, a part of which is in the realisation of invisible lines that criss-cross the site, linking the addresses and places of execution of Berliners, as built form.[2]

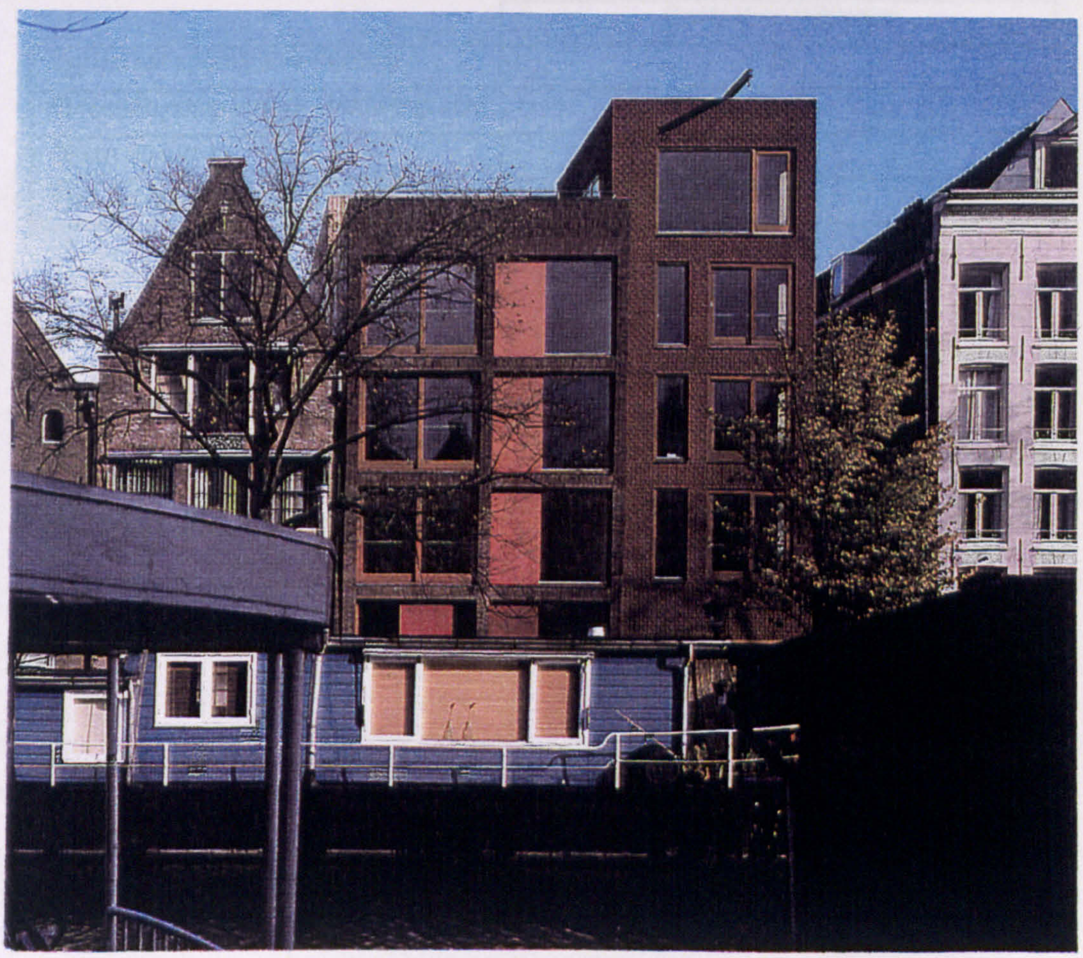
The criterion does not intend to promote any specific response; to do so would influence and inhibit the creative design process. Rather, it seeks to ensure that the contextual significance of the site and its surroundings are at least considered. The designer can then make the decision as to whether such elements or features will influence the design process of that specific dwelling or building.

In a typical housing estate built by a national house builder, the dwelling types will be taken

[1] Scott, Geoffrey. *The Architecture of Humanism*, London: Methuen, 1961, p. 3.
[2] Libeskind, Daniel. *Radix-Matrix: Architecture and Writings*, Munich: Prestel-Verlag, 1997.

from a pattern book. The selection will be based upon the potential market demand as opposed to the dwelling type most responsive to the local vernacular style or context. Therefore, the same dwelling types could be used in two projects at opposite sides of the country, and in fundamentally different contexts.

The Brouwesgracht apartment building by the Dutch architects Mecanoo can be used as a European comparative of best practice for this criterion. The seven apartments and one studio were located on a small in-fill site in Amsterdam. One of the challenges identified by the architects was how to insert a building into a historical urban context of 17th and 18th century brick townhouses on the canal side;[3] integrating a contemporary building into the *genuis loci* of the city. Through its materiality and distinction between public and private realm the building is at once both obviously new and carefully related to the architectural and urban nuances of its sensitive, historical context.



Brouwesgracht apartment building by Mecanoo[4]

[3] LeCuyer, Annette W. (ed) *Mecanoo*, Michigan Architecture Papers, Michigan: The University of Michigan, 1999.
[4] Source: Ibid.

Methodology of Assessment

Unsurprisingly the thesis has not established an objective, measurable way in which to assess the contextual significance of a site, due to the diverse ways in which that significance might be embodied. Therefore the assessment will propose the question: 'Has an evaluation of the contextual significance of the site, including empirical study and historical analysis of the site and its surroundings, been undertaken; has the significance, if any, been considered in terms of potential influence upon the design of the urban plan or dwelling design?'

Conclusion

The benchmark is based upon whether or not a masterplan and dwelling or dwellings have taken account of contextual influences in their design.

	Contextual Influence
Typical UK speculative dwelling	No
European comparative: Brouwesgracht	Yes
Drawn Study: 1	Yes
The 'urban house in paradise'	**Yes**

Contextual Significance of the Site benchmark for the 'urban house in paradise'

3.6 Deconstruction and Demolition: Recycling of Materials

As the recycling of materials turns a linear life span into a circular one, the impacts of materials arising from the demolition of a building could have two demands on the 'urban house in paradise', firstly if an existing building is demolished to clear the site for the dwelling, and then the demolition of the dwelling itself at the end of its lifecycle. The former is of particular relevance for the 'urban house in paradise' because its site is in an urban, brownfield area, rather than a greenfield site, and therefore there is an increased likelihood of having to clear the site of existing, even if derelict, structures. To reduce the consumption of natural resources, it is important in both cases that as greater proportion of the material arising is recycled as is achievable. As the recycling of the building in terms of use is considered under the criterion of Recycling of Building: Adaptability, refer to Annexe 3.29, here the benchmark is concerned with maximising the recycling of the materials that make up the dwelling.

In a 1992 survey was undertaken by the European Demolition Association on the recycling of construction and demolition waste in nine EC countries: Belgium, Denmark, France, Germany, Spain, Ireland, Netherlands, Spain and United Kingdom. The UK produced the second largest record of the quantity of construction and demolition waste, of 45 million tonnes in 1991, behind only Germany with 65 million tonnes. However, Germany also recorded the greatest quantity of recycling plants, along with Belgium and the Netherlands.[1] The consumption of aggregates, the material into which a high proportion of demolition waste can be recycled into, has grown substantially over the past decades, to 259 million tonnes in 1994, and is forecast to rise further, to between 330 and 365 million tonnes by 2006; this would equate to quarrying or mining on 3,100 to 3,500 hectares of land per annum.[2] The 'land bank' system, in which public authorities were expected to maintain reserves to meet a ten-year demand, has kept the cost of aggregates low, discouraging efficiency in use, and promoting the consumption of virgin material rather than recycling waste into aggregate.

In terms of the reduction of resource consumption, as put forward in *Factor Four*, the recycling of building materials presents obvious benefits. The substitution of recycled materials for primary resources has two-fold advantages. Firstly it reduces the amount of

[1] Department of the Environment. *Managing Demolition and Construction Wastes*, London: HMSO, 1994.

material extracted from the earth, and the consequent environmental damage that entails; secondly it cuts down on the quantity of waste sent to landfill, and therefore, in addition, reduces the production of methane from landfill, a gas which contributes to the greenhouse effect. This emphasises the importance of circularity in the lifecycle of materials, which has also been discussed under the criterion of Use of Reused and Recycled Materials, refer to Annexe 3.33. To maintain the circular nature of the life of materials, and not to fall back to an unsustainable linear pattern, it is critical to consider the material at the end of one revolution, when it has come to the end of its useful life for one period of use. Deconstruction or demolition can be thought of as both the end of one building's lifecycle or the start of another's, if the recycling of demolition materials is to be employed.

In 1991 the Department of the Environment commissioned a study into construction waste. It identified that there was scope for the recycling of both construction and demolition materials, and advocated that encouragement should be given to the establishment of recycling centres in urban areas.[3] As an example of the potential for recycling, the production of construction and demolition waste in the United Kingdom is in the region of 70 million tonnes per annum;[4] of this approximately 40 million tonnes are estimated to be hard materials suitable for the production of aggregate. However, at present only a fraction of this is sold as ground aggregate.[5] Only 4 percent of the United Kingdom's annual production waste arising from demolition undergo high level processing to produce secondary aggregate. Some materials, such as metal, which is predominantly steel, are recycled as a matter of course. For the material that is not subject to high level disposal, Golton suggests that 29 percent goes to low level use on or near the site, and the remaining 66 percent goes to landfill.[6] Other research commissioned by the Department of the Environment proposes that 29 percent of the total arising is put to low level use, whilst 30 percent is used for the engineering of landfill sites, and another 30 percent sent to landfill for disposal.[7]

Analysis has been made of the materials arriving at landfill sites. By percentage of volume, the primary materials are: soil and clay 44.4 percent, sand and gravel 17.5 percent, concrete 10.2 percent, brick 8.3 percent, bituminous materials, 5.3 percent, and wood 3.3 percent. It

---

[2] McLaren, Duncan, Simon Bullock and Nusrat Yousuf. *Tomorrow's World - Britain's Share in a Sustainable Future*, London: Earthscan Limited, 1998.
[3] Department of the Environment. *Occurrence and Utilisation of Mineral and Construction Wastes*, London: HMSO, 1991.
[4] Construction Information Research & Information Association. 'Construction Waste Minimisation', *CIRIA Spectrum*, London: CIRIA, 1999.
[5] Collins, R. J. and W. Sparkes. 'Blocks With Recycled Aggregate: Beam and Block Floors,' IP 4/98, *BRE Information Paper*, Building Research Establishment, October 1998.
[6] Golton, B. et al. *Demolition in Manchester - A Case of Long Distance Recycling*, 1995.

is estimated that at least 8 million tonnes of brick and concrete, 7 million tonnes of sand and gravel and 2 million tonnes of bituminous material could potentially be diverted from landfill through recycling.[8]

The recycling of building materials has strong precedents in a European context. For example, in the Netherlands and the Copenhagen district of Denmark both recycle over 80 percent of their demolition waste; it is legitimate to draw comparisons between the United Kingdom and Europe, as demolition produces similar proportions of masonry, such as brick, and concrete.[9] In Denmark this standard has been achieved through a high degree of commitment by the Government; landfill is severely restricted, and permission is granted for demolition only where the recycling potential of materials arising is maximised.[10] In Germany, a target was set that 60 percent of materials arising from building demolition was to go to reuse or recycling from 1995 onwards. Other research suggests that it should be feasible to recycle in the region of 75 percent of building materials.[11]

In 1991, in response to a proposed fourfold increase in landfill charges by the Canadian Ministry of Environment, a pilot project was proposed to test the concept of environmentally responsible demolition. The building to be demolished was an annex building of the Oakalla prison complex.[12] The demolition contract was offered to tender on the basis that contractors would 'channel waste away from landfills, toward reuse and recycling.' It was specified that bids should include two prices, one for traditional demolition, and the one for recovery, reuse and recycling. The outcome was that the latter was 24 percent cheaper than normal demolition. Of the total volume of material, it was estimated that the normal demolition process would have sent 92 percent to landfill; however, for the pilot project it was determine that only 5 percent was sent to landfill, and the remaining 95 percent was either reused or recycled.

Research in Australia demonstrated the potential for recycling demolition waste in Melbourne, where of the materials arising from the demolition of office blocks within the central business district 69 percent was being recycled, 11 percent for reuse and 58 percent

---

[7] Department of the Environment. 1994, Op. Cit. The report concedes that at present these values are based on a limited amount of data that is available, and that further detailed studies are required to establish reliable data.
[8] Ibid.
[9] Collins, R. J. 'The Use of Recycled Aggregates in Concrete,' IP 5/94, *BRE Information Paper*, Building Research Establishment, May 1994.
[10] Department of the Environment. 1994, Op. Cit.
[11] Lawson, W. R. 'Design for Deconstruction,' *First International Conference on Buildings and the Environment*, Garston: Building Research Establishment, 1994.
[12] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998.

for reprocessing. Bricks, timber, structural steel, floorboards and plumbing items had a recovery rate between 70 and 80 percent.[13]

A case study was undertaken by the Building Research Establishment into the potential levels of recyclability of building materials from demolition during the demolition of an existing building to make way for a new energy efficient office. It was determined through this live experiment that 96 percent by volume of the waste generated by the demolition of the existing building was reused or recycled. In addition, the demolition contractor was able to tender a lower contract price through the two-fold advantages of reduced waste disposal costs and income generated from salvaged materials.[14] This will evidently have an impact upon the lifecycle and construction cost benchmarks. However, there will be implications upon the overall construction time also, due to the additional time required for the deconstruction and separating of waste. In the BRE case study, two weeks were added to the contract period.

In the Greenwich Millennium Village project, it is proposed that 80 percent of the buildings are to be recyclable, achieved through specific specification of materials and construction systems.[15]

Although the potential recyclability of demolition waste was not a criterion considered in the initial drawn studies, it was proposed that at Allerton Bywater waste should be reduced by 50 percent throughout the supply chain process, and throughout the period of inhabitation of the dwellings. It is logical, therefore, that this benchmark should be carried forward beyond the occupation period, and ensure that 50 percent of the materials used within the dwelling are capable of being recycled upon demolition. The large quantity of concrete used in Drawn Study Five, establishing the technology of the drawn study dwelling, accounts for at least 50 percent of the material within the fabric of the dwelling, and will be capable of being crushed to form aggregates.

It is impossible to predict a generic numerical value the quantity of materials that will be in a dwelling, as the 'urban house in paradise' could be at once both a one person flat or a four bedroom terraced dwelling. Therefore, although it was an ambition of the thesis to quantify

---

[13] Salomonsson, Gustav D. and Carol MacSporran. 'Recycling of Materials in Building Construction', *Buildings and the Environment*, Proceedings of the first International Conference organised by CIB Task Group 8, 16-20 May 1994.
[14] Hobbs, G. and R. Collins. 'Demonstration of Reuse and Recycling of Materials: BRE Energy Efficient Office of the Future,' IP3/97, *BRE Information Paper*, Building Research Establishment, February 1997.
[15] Baldock, Hannah. 'Can Prescott Save the Village?', *Building*, 8 October 1999.

all of the criteria in dimensional terms for the benchmark of the quantity of material that is to be reused or recycled arising from the process of demolition, it will be necessary to use a percentage. Once this benchmark is applied to a particular dwelling, or even dwelling type, it can then be translated into a quantitative value if necessary.

Methodology of Assessment

The level of materials in the dwelling or building will be quantified by a percentage of their volume, as opposed to by mass. The percentage benchmark will then give a minimum target figure of the volume of material that should be either reused or recycled, or capable of being recycled at the end of the dwelling's design life span, and the remainder can be used to established a maximum target figure for the volume of material that should be disposed of to landfill. This can apply equally to existing buildings on the site or to the new dwelling.

Conclusion

On the basis of the examples given above, it should be possible for the recycling of demolition materials in the United Kingdom to reach the levels achieved in Europe. Therefore, the benchmark will be set at the level of 85 percent of the materials, measured by volume, arising from the deconstruction and demolition of the 'urban house in paradise', or an existing building on its site, should preferably be reused, and if not then should be recycled.

	Material to be reused or recycled (%)
Typical UK speculative dwelling	33
European comparative: Europahaus	> 80
Drawn Study: Number 5	50
The 'urban house in paradise'	**85**

Deconstruction and Demolition benchmark for the 'urban house in paradise'

3.7 Density: Quantitative

Density is an example of a criterion that will be posses both objective and subjective values. The 'urban house in paradise' will have an ideal density affected by its desired urbanity; this will be the social, qualitative value. However, there is also a proposed critical level of density required for sustainable development. Urban densities can vary significantly between different cities. For example Barcelona, which is one of the most compact European cities, has an average density of 400 dwellings per hectare; whereas relatively dense areas of cities in the United Kingdom, such as Bloomsbury and Islington in London, may up to 200 dwellings per hectare.[1]

It has already been established within the thesis that land is a natural resource, for example through its provision of wildlife habitat. The density of a project is, in effect, a measure of the efficiency with which the land that the project occupies is being used; the higher the density, the more efficient the land use. However other factors must be considered, as this may be considered an avocation of 'town-cramming'. These factors included the social impact of increasing density. The re-issue of Planning Policy Guidance (PPG) 3, requiring an increase in the density of residential development from typical levels for reasons including the increased efficiency of land use, is indicative of the contemporary relevance of this criterion.

There is a diverse range of units for quantifying density; these include people per hectare, dwellings per hectare, habitable rooms per hectare, and plot ratio. Residential densities can also be considered in terms of gross or net values. Gross residential density (GRD) is determined by dividing the population by the total geographical area; net residential area (NRD) deducts the area that is occupied by open spaces and non-residential land.[2] It is suggested that the NRD value can be between 1.5 and 3 times higher than GRD.[3] Annex C to PPG 3[4] contains a more specific definition of net density, which includes only those areas that will be developed for housing and directly associated uses.

This will include:	It therefore excludes:
access roads within the site	major distributor roads
private garden space	primary schools
car parking areas	open spaces serving a wider area
incidental open space and landscaping	significant landscape buffer strips
children's play space (where applicable)	

[1] Urban Task Force. *Towards an Urban Renaissance*, London: E & F N Spon, 1999.
[2] Fulford, Charles. 'The Compact City and the Market'; in Jenks, Mike, Elizabeth Burton and Katie Williams. *The Compact City – A Sustainable Urban Form?*, London: E & F N Spon, 1996.
[3] McLaren, Duncan. 'Compact or Dispersed? Dilution is No Solution', *Built Environment*, Volume 18 Number 4.
[4] DETR website, 9 March 2000: www.planning.detr.gov.uk/ppg3/9.htm

One of the principal causes of the requirement for 3.8 million new dwellings new dwellings by 2021[5] is demographic change. For example, inhabitation patterns are changing, and there is a predicted increase in the number of people living on their own or co-habiting. This raises one of the issues of benchmarking density. If a value is proposed on the basis of the number of bed spaces in a dwelling, then an account may need to be taken for the fact that the designed occupancy level may never in reality be achieved. This may be exacerbated by an increasing trend of working from home, when a bedroom may be used as an office.

For the purposes of consistency, within the thesis residential density will be considered in terms of people per hectare ($p.h^{-1}$). Values used from other sources will be converted into $p.h^{-1}$. Where these conversions are from dwellings per hectare, the occupancy level will be taken as 2.4 people per dwelling; this is the mean household size in Great Britain, based on data from the 1995 General Household Survey.[6] Of course, it should be appreciated that this figure is likely to continue to fall in the future under the demographic changes outlined above.

In *City Sense City Deign*, Kevin Lynch (1918-1984), a leading American environmental design theorist, identified certain qualities of the urban environment in respect to density. This analysis is summarised as follows,[7] (figures have been converted from people per square mile to people per hectare for consistency):

- **3.9 people per ha**. Very few cities have such a low density as this, which is verging on rural land, Canberra is one of only a few examples. Problems of transportation, with a car becoming a necessity, and social cohesion, are inevitable at a density as low as this, in addition to land wastage.
- **13.5 people per ha**. Typically the density of the average American suburb, some large cities have a density of this order, such as Los Angeles.
- **38.6 people per ha**. At this level, an urban structure is reached in which the dominant residential type is group housing, such as row and two-family houses; a density exemplified by cities such as Baltimore and Washington or, in England, Harlow. Chicago is above this level, at 61 people per ha. Retaining private gardens, a typical layout is tighter than suburbia, with greater visual and social cohesion. Few historical cities, where defence was paramount, were as dispersed as this.

[5] Department of the Environment, Transport and the Regions website, 2 July 1999: www.housing.detr.gov.uk/information/keyfigures/index.htm
[6] Office for National Statistics. *Living in Britain – Results from the 1995 General Household Survey*, London: HMSO, 1996.
[7] Banerjee, Tridib and Michael Southworth. *City Sense and City Design - Writings and Projects of Kevin Lynch*. Cambridge, Massachusetts: The MIT Press, 1996, p. 37-38.
[8] Jenks, Mike, Elizabeth Burton and Katie Williams. *The Compact City – A Sustainable Urban Form?*, London: E & F N Spon, 1996.

- **135 people per ha**. With three to four storey apartments, a density is reached comparable to the centre of most American major cities, or Florence. A stronger sense of urbanity and improved social intercourse are felt at this level, although as are the beginnings of congestion.
- **386 people per ha**. Comparable to Manhattan, Damascus, Naples and Rome, this is the upper end of the density scale; areas formed by densely set apartments.

However, one shortcoming of Lynch's analysis is that he does not provide any qualification as to the process of calculating these densities; for example, as to whether they are gross or net. This difference can have a dramatic effect, as the following table demonstrates:

City or Region	Residential Density ($p.h^{-1}$)	
	Gross	Net
London	56	168
Hong Kong	293	879
Los Angeles	20	60
Melbourne	16.4	49.2
Paris	48.3	144.9
Tokyo	105.4	316.2
Toronto	39.6	118.8
Camden (London)	56	168
Haringey (London)	66	198
Islington (London)	-	740
Milton Keynes	-	67.5

Table of gross and net residential densities for selection of cities and regions[8]

From this table, by comparing the values for Los Angeles, it can be determined that Lynch's figures are gross residential densities, and therefore that the net residential densities are likely to be between 1.5 and 3 times higher than the values given.

A matrix for determining the residential density of new housing developments has been proposed by the British architectural practice Llewelyn-Davis.[9] It takes into account the location of its site, the existing urban fabric, i.e. its context, and the predominant proposed dwelling type. Values can then be determined for a recommend density range. Originally

[9] Hattersley, Lia. 'Density Formula Packs Them In,' *Building Design*, 16 July 1999.

quantified as habitable rooms per hectare, their proposals can be translated into people per hectare in the table below for the purposes of comparability.

		Option 1	Option 2	Option 3
	Parking Provision	High: 2 to 1.5	Moderate: 1.5 to 1	Low: < 1
	Predominant type	Detached, linked	Terraced , flats	Mostly flats
Site Location	**Setting**			
Within town centre	Central			690 to 950
	Urban		200 to 450	475 to 740
	Suburban		150 to 250	265 to 370
Close to centre or transport link	Urban		200 to 300	320 to 475
	Suburban	150 to 200	200 to 250	
Currently remote	Rural	150 to 200		

Chart of proposed residential densities (people per hectare) by Llewelyn-Davis.

This table demonstrates the densities considered appropriate to different settings, rural, suburban and urban. As the thesis is predicated toward urban housing, this will focus the study of the density criteria and benchmarks above a threshold level. From the table above, this threshold can initially be proposed as 200 people per hectare.

Typical greenfield residential developments, according to research by Friends of the Earth, rarely exceed net residential densities of 100 people per hectare. If this were at a mean occupancy level of 2.4 people per dwelling, it would equate to a housing density of 42 dwellings per hectare. More probable is that it is a design density, and therefore based on the total occupancy that the dwellings are designed to accommodate; if this were a typical average of 4 people per dwelling,[10] it would equate to 25 dwellings per hectare. This highlights the significance in making a distinction between the density achieved on the basis of the number of people the dwellings were design to accommodate, or on the typical occupancy level. Empirical research shows that this value may be lower, but certainly is not often higher. Based on designed occupancy levels, selected developments were determined to have densities in the region of 90 people per hectare.[11] Other research shows that new residential development in England is between 20 and 39 dwellings per hectare net.[12] The national average density for greenfield housing, as determined by the

[10] Derived from the analysis for the Space Standards benchmark, refer to Annexe 3.30.
[11] A number of new build housing developments were selected, and their densities determined on the basis of the number of bed spaces for the mix of house types available.
[12] Fulford. Op. Cit., p. 130.

Urban Task Force, is 22 dwellings per hectare.[13] At a typical designed occupancy level of 4.5 people per dwelling, this would equate to 99 people per hectare; although based on the mean occupancy level of 2.4 people per dwelling, this would equate to a density of 53 people per hectare.

The residential density of Drawn Study One, the design of the urban block in Glasgow, can be calculated as a comparative value. Although the block is multi-functional, the entire area of the site is used in the calculation as all of the functions are contained within a single block with the part of the containing the dwellings covering the other functions. Therefore a proportion of the 0.32 Ha area of the site cannot be removed which accommodates solely other functions. Taking a mean value of the mixture of dwelling sizes, due to the adaptable nature of the block, a density of 350 $p.ha^{-1}$ is achieved. This can be compared to the net density of Drawn Study Three, as Allerton Bywater is a very different context using a different typology of dwelling. The density was calculated as 203 $p.ha^{-1}$.[14]

In a recent announcement, the Deputy Prime Minister John Prescott proposed that the Government would only consider housing developments where the density is between 30 and 50 $d.h^{-1}$, in connection with the announcement of new housing figures for the Southeast.[15] The recent reissue of PPG 3 confirms this intention, stating that, "Local authorities should ... avoid developments which make inefficient use of land (those less than 30 $d.h^{-1}$ net); [and] encourage housing development which makes more efficient use of land (between 30 and 50 $d.h^{-1}$ net).[16] Converting these values to people per hectare gives a range of between 72 and 120 $p.h^{-1}$. The Department of the Environment, Transport and the Regions comments that densities over 120 $p.h^{-1}$ may be appropriate in inner urban areas.

In the national press recently, it is claimed that John Prescott's advisors believe that a figure of 435 $d.h^{-1}$ can be achieved in urban areas.[17] They suggest that this density could be created with an urban fabric such as that of Islington, with 4 to 5 storey terrace dwellings. Assuming that this value is net,[18] this would equate to a density of 1,044 $p.h^{-1}$. This value appears extraordinarily high in the context of the analysis in the preceding paragraphs, and as such should be treated with a degree of caution.

---

[13] Urban Task Force. Op. Cit.
[14] Refer to Drawn Studies One and Five in volume 2.
[15] Nuttall, Nick. 'Prescott aims to cut urban sprawl', *The Times*, Wednesday 8 March 2000.
[16] Department of the Environment, Transport and the Regions website, 9 March 2000: www.planning.detr.gov.uk/ppg3/
[17] Prescott, Michael. 'Prescott to curb urban sprawl with terraces', *The Sunday Times*, 6 February 2000.
[18] It is assumed that it is net, as if it were gross it would equate to a net value in the region of 2,349 $p.h^{-1}$, which is very high, (Hong Kong has a net density of 879 $p.h^{-1}$).

Friends of the Earth advocate a net residential density of 225 to 300 $p.h^{-1}$ as sustainable, and up to 370 people per hectare as appropriate and sustainable in central accessible urban areas.[19] These values are based, at least in part, on studies carried out by Peter Newman and Jeff Kentworthy which reveal that public transport use becomes significantly more viable at net residential densities over 90-120 persons per hectare, and walking at over 300 persons per hectare. However, they also relate to the efficiency of land use. The dwelling type that Friends of the Earth associate with this density is the equivalent of the Georgian three to four storey terrace.[20]

There is an evident disparity if the densities proposed by PPG 3 and Friends of the Earth are compared, between 72 and 120 $p.h^{-1}$ for the former and 225 to 300 $p.h^{-1}$ for the latter, or 370 $p.h^{-1}$ if the Friends of the Earth urban density is used. However, PPG 3 is setting down minimum values that are at the lower end of a range of acceptable densities, in terms of guidance for avoiding developments that are profligate in terms of land use efficiency. The PPG 3 range also applies to all developments, whereas the benchmark for the 'urban house in paradise' is predicated toward urban dwellings. This would suggest that the density should be well above that of the PPG 3 recommendation.

In essence, some of the advantages and disadvantages of high and low densities are put forward in the following bulletpoints:

- Low-density developments are an inefficient use or land, which is a valuable resource. Even if a site is 'brownfield', it could be argued that inefficient use of land here might lead to greenfield development elsewhere.
- Most amenities and non-dwelling functions require a threshold population in order to sustain themselves. A higher density will allow for an increased number of mixed functions and non-housing facilities, through creating a higher population.
- The higher the density value is, the less area is available for private open space. Therefore more reliance will have to be made upon useable, secure and high-quality public open space to compensate for this.
- The values proposed are high, and will require particular dwelling types, such as terraced units and flats, to achieve them. This may well have an impact upon the perceived desirability of the dwellings and the nature of the target population who will account for the population over and above the existing that will remain.

---

[19] Jenks, Mike, Elizabeth Burton and Katie Williams. Op. Cit. p. 130.
[20] McLaren, Duncan, Simon Bullock and Nusrat Yousuf. *Tomorrow's World*, London: Earthscan, 1998; and Newman, Peter and Jeff Kentworthy in Jenks, Mike, Elizabeth Burton and Katie Williams. Op. Cit.

- Dwelling forms such as terraced units and flats are typically more energy efficient than the semi-detached and detached forms associated with low-density development. The Building Research Establishment calculated that intermediate flats require 66 percent less energy per unit floor space than detached houses.[21]
- Preconceptions can be common in terms of proposing high-density living, and associated with high rise tower blocks. This will require communication to overcome these preconceived associations of the relationship between lifestyle and density.
- As has been outlined above, the use of public transport and walking as means of transportation increases with density. The thresholds of 91 to 120 $d.h^{-1}$ in the former and over 276 $d.h^{-1}$ in the case of the latter have been suggested.[22]
- A higher density can provide both sufficient population levels to sustain non-dwelling amenities and mixed functions, and if high enough encourage walking to use those services through their proximity.
- One way in which to achieve higher densities is to reduce the provision of car parking spaces per dwelling. This increases the efficiency of land use. However, if car use is to be discouraged, which may be required in order to justify reduced parking provision, sufficient attractive alternatives, in terms of public transport, would likely need to be provided

The sustainable density value proposed through research by Friends of the Earth will provide another base figure for residential density, in addition to PPG3 and Llewelyn-Davis base value, of at least 300 $p.h^{-1}$. From this the value can be refined through other criteria, including qualitative benchmarks to define the quality of the environment that is being created. However, as the thesis is predicated toward benchmarking urban dwellings, the benchmark should also respond to the Friends of the Earth value of 370 $p.h^{-1}$ for urban locations, to maximise the efficiency of land use, which is a valuable natural resource. Therefore, this will become the base benchmark for the 'urban house in paradise'.

Although there are examples of projects with a higher density, the Hooikade housing project in Delft by the architect Kees Christiaanse has been selected as a comparative of best practice as it has a density in close comparison to that proposed for the 'urban house in paradise'. Therefore it can serve to demonstrate the scale of urban form required to achieve that density. This project for 140 owner-occupied dwellings has apartments distributed across four individual blocks, which are arranged to form a noise barrier between the passing

---

[21] Building Research Establishment. *Energy Conservation: A Study of Energy Consumption in Buildings and Means of Saving Energy in Housing*, CP 56, Garston: Building Research Establishment, 1975; in McLaren, Duncan. 'Compact or Dispersed? Dilution is No Solution', *Built Environment*, Volume 18 Number 4.

trains on a nearby railway and the residential area behind. The net residential density across the site is 378 people per hectare.

The underlying theme explored in this project is a re-invention of the gallery, or deck access, dwelling. The skin of the bocks was conceived as an envelope folded around the actual building volumes that yielded itself like a cloak to the various urban situations that confronted it. The lozenge-like form of the envelope is intended to moderate the transition gaps between the blocks, and takes up the direction and orientation of the side streets that permeate the project. The wedge formed stairwells visually limit the dimensions of the side streets. The biggest block is twisted in order to divide the building volume and to connect to the existing urban fabric.

Methodology of Assessment

The unit of measurement that has been selected to quantify the value of the benchmark is net residential density (NRD), and this will be quantified in terms of people per hectare in terms of the designed occupancy level of the dwelling. The calculation of that value, in terms of what functions and spaces are included and excluded will follow the guidelines set down in Annex C to PPG3, as given above. The site area will be established, including access roads within the site, private garden space, car parking areas, incidental open space and landscaping and children's play space. The total number of inhabitants that the dwelling or dwellings are designed to accommodate is then divided by this value.

Conclusion

Therefore, the proposed benchmark for the criterion of carbon intensity for gas boilers, seen in the context of the other comparative benchmarks of the typical speculative dwelling and Drawn Study One: Glasgow – Scale of the Urban Block, is proposed in the table below:

	Net Residential Density ($p.ha^{-1}$)
Typical UK speculative dwelling	< 100
European comparative: Hooikade	378
Drawn Study: 1	350
The 'urban house in paradise'	> 370

Density: Quantitative benchmark for the 'urban house in paradise'

[22] Ibid.

3.8 Density: Qualitative

As commented above, density is not just a quantitative issue, particularly for urban housing where development is likely to occur within close proximity to an existing grain of buildings. Frequently there will be a predominant scale to this existing fabric, and the response to this fabric, in terms of the three dimensional scale of the new building or buildings, should be considered. To some extent this criterion will exist in parallel to that of the Contextual Significance of the Site.

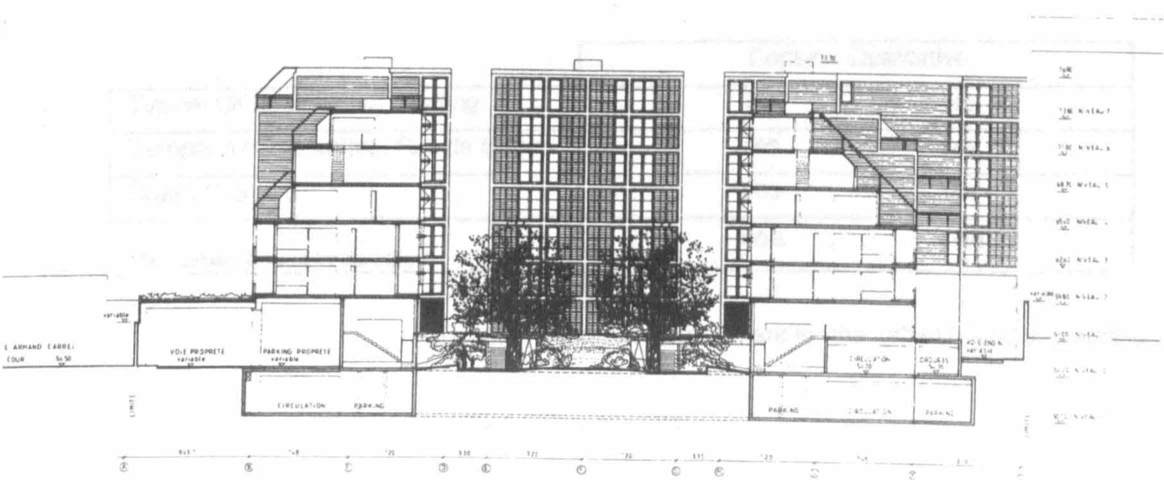
Firstly the density or scale of the surrounding fabric should be established; this will be an empirical study of the context of the site. A decision should then be made, in conjunction with the Contextual Significance of the Site to determine the value of those surroundings, to establish the degree of response or influence those surroundings should have upon the design of the new dwelling or dwellings.

The qualitative value of density will also apply to the articulation of mass within the site itself, irrespective of the surroundings. This will relate to the social sustainability of the density proposed, and will relate in part to the criterion of Green Space, refer to Annexe 3.18. To avoid any tendencies toward what might be considered as 'town cramming', in counterpoint to the increased density of the dwellings there should be an adequate provision of open space. This could be in the form of private gardens, semi-private communal spaces or public open space, and could be either green or hard landscape. As the matrix of criteria that defines the 'urban house in paradise' does not intend to impinge upon the creative design process, no guarantee can be made of the quality of the design of such spaces; this is beyond the scope of the criteria but is considered in part in the subjective criteria that could form an accompaniment to the criteria of the 'urban house in paradise'.

Unlike, for example, Energy Consumption: Inhabitation, there is not a predefined way in which to assess the qualitative value of density, largely due to its subjective nature. Therefore the thesis proposes a way in which such an evaluation could be made.

In Drawn Study Three, for a part of the masterplan of the Allerton Bywater Millennium Community, the density of dwelling was increased within areas of housing, and balanced through the provision of open space. The primary routes included both hard and green open space, allotment gardens and sheltered parks were included within the cores of housing areas, for dwellings in the immediate vicinity, and hard public open spaces were created at the centre and in key locations. The density of both traditional dwellings in the area, and also of notable precedents of Yorkshire villages, was responded to in the design of the plan.

The Rue de Meaux housing project in Paris by Renzo Piano is considered an exemplary demonstration of a qualitative response to density. The complex of 220 flats and maisonettes are set around the periphery of a rectangular garden. The two short sides of the rectangle are cut vertically, dividing the facade into three elongated blocks that are in proportion to the surrounding buildings; the central space corresponds to the grain of a medium-sized Parisian street; however its character is very different; showing a contemporary response to the qualitative density. The massing and vertical scale of the perimeter of the block, where the dwellings are located, which are orientated either into the courtyard of toward the street, responds to the height and scale of the surrounding urban fabric.



Rue de Meaux housing, Paris by Renzo Piano[23]

Methodology of Assessment

The thesis has not established an objective, measurable way in which to assess the qualitative density of a design, due to its the inherently subjective nature. Therefore the assessment will be based upon proposing the following questions. Firstly, does the design provide the right integration between a high density of activity and dwellings necessary to

[23] Source: The Architectural Review, March 1992.

support the area, in terms of sustainability and efficient use of land, and open, green and hard space? Secondly, has due consideration been given to the arrangement and massing of the scale of the new building or buildings, and the correct degree of response been made to the morphology of the surrounding fabric, if deemed appropriate? Therefore the quantitative values proposed above can be informed by these two qualitative benchmarks. To achieve compliance with the benchmark, the answer 'yes' should be capable of being made to both questions.

Conclusion

The benchmark is based upon whether or not a masterplan and dwelling or dwellings have taken account of qualitative influence of density in their design. Therefore, the proposed benchmarks for the criterion of qualitative density, seen in the context of the other comparative benchmarks of the typical speculative dwelling and Drawn Study One, is proposed in the table below.

	Density: Qualitative	
Typical UK speculative dwelling	No	No
European comparative: Rue de Meaux	Yes	Yes
Drawn Study: 3	Yes	Yes
The 'urban house in paradise'	**Yes**	**Yes**

Density: Qualitative benchmark for the 'urban house in paradise'

3.9 Design Life Span

The implication of time, and therefore the period of the lifecycle of the dwelling, is likely to have a highly significant impact upon the overall perception of the sustainability of a project. Whole-life philosophy is a critical issue in the consideration of the 'urban house in paradise'. For example, whereas the Construction Taskforce, in their initial report, proposed reductions in costs year on year in terms of the construction only, the Movement for Innovation, the body charged with the interpretation of the recommendations of the Construction Taskforce into reality, extended the applicability of its aims to include ten percent improvements each year in lifetime costs. However, at present there is no definition of what the scope of lifetime costs would include, or how the lifetime of a building is defined.[1] The significance of time is highlighted through the large proportion of the criteria that define the 'urban house in paradise' that are benchmarked in a unit of magnitude that includes time as a dimension. For example, energy consumption as $kWh.m^{-2}.a^{-1}$, water consumption as $l.p^{-1}.d^{-1}$, CO_2 emission as $kgCO_2.m^{-2}.a^{-1}$.

Variety in the definition of the period of time considered as the lifecycle of the dwelling would significantly effect the overall level of sustainability of the project. Evidently, the re-building of a dwelling every few years would be unsustainable. However, the implication of lifecycle goes beyond such literal and straightforward interpretations. For example, savings made during construction through, for example rational construction methods, could be re-embodied in increasing the energy performance of the dwelling, thereby maintaining the typical construction cost, but creating long term savings in both financial and ecological terms. Clearly the magnitude of such savings will be significantly affected by the length of time over which such factors have an impact, i.e. the period of lifecycle. The potential period in which to pay back increased capital cost investment will be increased if the life span of the dwelling is maximised.

In addition, the value of lifecycle may also vary in its period of appropriateness, in particular in the owner-occupied market. The benefits of increased performance may have to be proven to have value in shorter periods of time, for example the typical mortgage period of twenty-five years, or even in the typical length of ownership of five years. If people move on average every five years, would any additional cost of increased performance standards have to be reaped within that period? Or could it be argued that such attributes would have an equal value in the sell-on cost of the dwelling? Such consideration may indicate the potential applicability of the matrix of criteria of the 'urban house in paradise' in terms of its future market. The rented sector, both public and private, are more likely to be concerned with the implications of the full life span of the dwelling, as

[1] Movement for Innovation website, March 1999, www.m4i.org.uk. However, the inclusion of lifecycle cost was subsequently removed from the website, and replaced with construction cost again.

oppose to a shorter period of occupancy, as the owner of the building will have a longer term involvement than the occupier.

Two attitudes could be adopted. Firstly a lifecycle figure could be proposed by the thesis; this would be a generic, average figure that, as determined by the research, is a mean value of the life span of a typical urban dwelling. This would satisfy the purpose of an assessment that determines the sustainability of a dwelling over its entire life span. However, the assessment is then reliant on a factor over which it has no influence, and that overall sustainability could change dramatically if the dwelling's life span were in reality longer or shorter than the benchmarked mean, due to many criteria being quantified in time dependant units of magnitude. The second attitude that could be adopted is that the lifecycle would become a variable criterion within the matrix. A proposed function of the assessment of the 'urban house in paradise' is that it will measure the consequential effects of benchmarks upon each other, and clearly varying the period of lifecycle will have a significant consequential effect on several benchmarks. This would also account for variations in the interpretation of the appropriate 'lifecycle' of the dwelling.

The overall aim of the thesis is to produce a matrix of criteria and an assessment methodology that is a measure of the overall sustainability of a dwelling. In order to do this, its total lifecycle must be considered, as sustainability requires a whole-life perspective.[2] Therefore the thesis will determine a value of the lifecycle benchmark for use within the matrix of criteria. However, due to the significant effect which altering that value may have, the assessment methodology will allow this figure to be a variable value. Therefore it will be possible to determine, for example, the total energy consumption, CO_2 emission and the overall sustainability of a dwelling with a lifecycle of *x* years, and compare this for a lifecycle of *y* years. In this way, the magnitude of the consequential effect of varying the design life span can be demonstrated also.

The benchmark value attributed to the lifecycle criterion could be based upon the value of the minimum design life attributed by the British Standard BS 7543,[3] to the category of buildings within which new dwellings are covered. Defining the lifecycle of a dwelling by the minimum designed life span would determine the effects of the efficiency criteria. The BSI classification for new dwellings is category four, and the value is a minimum of 60 years. In the case of the assessment methodology being applied to a refurbishment project, an appropriate consideration bearing in mind that the thesis is predicated on urban housing, then BS 7543 states that the

---

[2] The value and significance of lifecycle analysis (LCA) has been well documented.

[3] British Standards Institute. BS 7543 - Guide to Durability of Buildings and Building Elements, Products and Components, London: HMSO, undated.

[4] Research Steering Group of the Building Surveyors Division and the Building Research Establishment. *Life Expectancies of Building Components*, London: The Royal Institute of Chartered Surveyors, August 1992.

minimum design life span for this, category 3, is 30 years.

Prolonging the design life span of a dwelling would have at least two significant benefits in terms of sustainability. First is the increased time span over which factors such as increased insulation standards can have an affect on overall the savings in lifecycle terms; the longer the design life span, the longer the period over which savings will be accrued, provided that the element is still efficient in relative terms, as will be discussed next. Secondly, the longer the design life span, the longer the period of time over which the initial embodied energy input of materials is being utilised. Even if one hundred percent of the dwelling's materials are recycled, there is an embodied energy input into the recycling and construction or assembly processes, and therefore the longer the period of each cycle of material use, the more efficient the material usage becomes.

An additional consideration is that whilst the building itself will be one lifecycle consideration, there will also be the aggregate lifecycles of its constitute parts, such as components and servicing to consider. For example, the effective lifecycle of the heating system is liable to be less than that of the building. With increasingly efficient systems being developed constantly, there may be a critical moment at which it will be beneficial to replace the heating system with one that is more efficient, or alternatively it will have to be replaced at the end of its life span. This will have an unpredictable effect on the lifetime energy consumption of the building, as it will be very difficult to make accurate presumptions about the degree of increasing efficiency. The variability of lifecycles within a dwelling is demonstrated by examples in the table overleaf.

Component	Life Expectancy (years)	
	Mean	Maximum
Stone	130	500
Brickwork	105	300
Render finish	42	200
Weather boarding	33	150
Clay roof tiles	68	100
Concrete roof tiles	46	100
Windows and doors - hardwood	66	300
Windows and doors - softwood (painted)	32	150
Windows and doors - softwood (uPVC)	32	75
Light fittings	22	50
Gas-fired boilers	20	50
Steel panel radiators	22	50
Electric immersion elements	14	50
WCs	37	200
Baths - plastic	20	75
Baths - steel	32	80
Shower units	13	75

Mean and maximum predicted life expectancy of some common building materials and components[4]

As discussed under the Thermal Performance benchmark, because the envelope of the dwelling has the longest life span, its level of performance should be as high as possible. As can be seen in the table above, the fabric materials of brick and stone have life spans well above 60 years. Therefore, in order to improve the gains in efficiency made by the additional investment, both in economic and embodied terms, and to increase the efficiency of the embodied energy input into the dwelling, it is proposed to increase the life span benchmark of the 'urban house in paradise' from that of BS 7543.

The benchmark was chosen to be as near as possible to the overall life span of the external fabric of the dwelling, but to also be within close proximity to complete lifecycles of other elements with shorter lifecycles which may be replaced, or upgraded, during the overall life span of the dwelling. For example, with a small amount of innovation in prolonging the lifecycle of the element, the overall life span will be two lifecycles of concrete tiles, two lifecycles of hardwood windows and three lifecycles of painted softwood windows.

In order to make the maximum use of the materials used to construct her Oxford Solar House, the architect, Dr Susan Roaf, set the benchmark of a minimum design life expectancy of 200 years.[5] According to the data in the *Life Expectancies of Building Components* report,[6] the facing brickwork from which the house is constructed will have to significantly out perform the mean life expectancy of that material, which is 105 years if it is to last the life expectancy of the dwelling; as the maximum value is 300 years it could be an achievable target. However, according to data in the report, the concrete roof tiles will have to be replaced at least once, as their maximum estimated life is 100 years, and the mean is 46 years.

During the evolution of Drawn Studies Four and Five, an assumed value of the design life expectancy of the dwelling was made. At 100 years this is above the design life expectancy required of a typical dwelling. This value is in line with the maximum life expectancy that was considered appropriate for concrete blockwork and stone cladding.[7]

In order to achieve an increase in the life expectancy of the dwelling, without making significant increases in maintenance and the replacement of elements of the external fabric, careful specification will be required. This will also have to be reconciled with other implications of material selection to create a balance between the life expectancy of the dwelling and its component parts, the level of embodied energy used in the extraction production, processing and transport of those materials and components, and other ecological impacts of those materials, such as the depletion of finite natural resources.

The benchmark proposed for the design life span of the dwelling must reflect the life span of the materials that are used in the construction of dwellings. It would be irrational and futile to propose a benchmark that cannot be achieved through the life expectancy of the materials that form the primary structure of the dwelling. Setting the benchmark too high for the life span of the dwelling may also mean that only a limited selection of materials can be used to create the structure of the external envelope, which might force the selection of less sustainable choices. This is where the interrelated structure of the matrix of benchmarks will assist in determining the best overall balance of choices between life span and embodied energy.

[5] Roaf, Dr S. and Dr M. Fuentes. 'Demonstration Project for a 4kW Domestic Photovoltaic Roof in Oxford – Volume One', *ETSU Report S/P2/00236/REP/1*, London: ETSU, 1999.
[6] Research Steering Group of the Building Surveyors Division and the Building Research Establishment. Op. Cit.

Methodology of Assessment

The benchmark will be a design target, as the life span of a building cannot be determined with any higher degree of accuracy at the design stage. The life span will be based upon the life expectancy of the materials from which the primary structural envelope of the dwelling has been constructed, as proposed under the Research Steering Group of the Building Surveyors Division and the Building Research Establishment's *Life Expectancies of Building Components*. Once this has been determined, the impact of that life span on the other materials and components used in the dwelling can be determined, in terms of how frequently they will have to be replaced, and therefore how many times they will be replaced during the design life span. The impact of this in terms of construction and maintenance cost can then be determined, as well a lifecycle analysis of the energy consumption of the dwelling. This will be based upon the initial embodied energy in the dwelling, the embodied energy of maintenance throughout the design life span, and the annual energy consumption during the period of inhabitation.

Conclusion

Therefore, the comparative benchmarks and the proposed benchmark level of the life span of the 'urban house in paradise' are as summarised below:

	Design Life Span (years)
Typical UK speculative dwelling	60
European comparative: Roaf OSH	200
Drawn Study: 5	100
The 'urban house in paradise'	**120**

Design Life Span benchmark for the 'urban house in paradise

[7] Ibid.

3.10 Diversity

The architect Hans Kollhoff wrote:

> 'Housing' is a functionalist, anti-urban concept ... that attempted to deal with the chaos and conflicts of the city by means of a simple and clean strategy, but on the unfortunately turned out to be boring and destructive of the complexity and refinements of urban environments.
>
> Rather than talk about 'housing', or even 'dwelling', I would suggest that we consider 'urban building' to be the issue at hand, in all its complexity and contradictions. Every urban settlement is liveable and ecological, it dwelling is a decisive part of its structure. And in return dwelling, enriched by an urban complexity of functions, becomes 'habitation' ...[1]

Clearly, diversity and difference in the mixture of functions is a critical part of Kollhoff's view of dwelling within the multiplicity of functions that create a city. His view of mono-functionalism is one of banality, which is at odds with the complex juxtaposition of functions that are an integral attribute of the urban environment.

However, the benefits of programmatic diversity are not limited to a reflection of complexity of the city and consequent alleviation of monotony. The mixture of functions can also be considered crucial to the potential sustainable urban form of the compact city, or the 'city of short distances'. This criterion relates to the tangential issue of transportation, identified in the Chapter 1, refer to volume 1, as another element which, like the dwelling, needs to be integral to a wider drive to increasing overall sustainability. It is also an example of where the criteria of that define the 'urban house in paradise' move beyond the scope of just the dwelling, and into its surroundings.

Increasing the programmatic diversity of a project beyond just that of housing, and therefore providing other functions in close proximity to the dwellings, could reduce cars use, and increase the likelihood of people walking to use those services. For example, in a medieval Italian city such as Florence there was a huge diversity of functions within a short walking distance of any point within the city. This would have the dual benefit of reducing local

---

[1] Kollhoff, Hans, 'Urban Building Versus Housing,' *Lotus*, Number 66.

pollution arising as a consequence of emissions and reducing the consumption of non-renewable fossil fuels.

The mono-functional housing developments typically produced on greenfield sites by national house builders typify the banality and lack of the complexity and refinements of urban environments identified by Kollhoff. Research suggests that such dwellings on such developments produce on average six to seven car journeys per day, counting those to and from the dwelling as two.[2] These developments, through only encompassing one function and poor location to services, result in the use of cars to access other facilities.

An advantage of locating a multi-function project within an urban context is that the number of occupants within a project need not provide the critical population required to sustain the functions other than housing, due to the existing population. The range of functions that could be encompassed within a project is very broad and could relate to either the inhabitants or the surrounding urban environment. These functions could include, subject to commercial viability, retail, commercial, workshops, recreational facilities, kindergartens, doctor's surgeries and cafes or bars.

As this is a criterion that is not included within any other assessment methodology, a way in which to quantify the performance of a project against it had to be devised. This had to account for the variety of scales that urban dwelling projects might be, which would affect their capacity to sustain other functions. The most straightforward way in which to quantify this in generic terms was considered to be dividing the number of functions within a project by the area of its site. This would be directly comparable to the calculation to ascertain the quantitative density of a project, refer to Annexe 3.8, and therefore would minimise the additional information required to undertake the evaluation.

The Prisma development in Nuremberg, Germany is an ideal example of a mixed function urban block. It was designed by the German architect Joachim Eble as a catalyst for the area, and as a mixed function, socially balanced complex, underpinned by ecological and energy saving principles. It encompasses 61 flats, 32 office units, 9 shops, a café and a kindergarten.[3] This total of potentially 13 different functions occupies[4] an area of 3,122 m²

---

[2] Personal communication with John Whitelegg, Professor of Environmental Studies, Liverpool John Moores University.

[3] Dawson, Layla. 'Walled Green City, *The Architectural Review*, Number 1205, July 1997.

or 0.3122 ha. Using the methodology outlined above, this can be translated into a benchmark of 41.6 functions per hectare.

The urban block in Drawn Study 1 also encompassed a number of functions, including dwelling, commercial spaces, between 10 and 18 retail units and a café or bar. Using the same methodology, this can be benchmarked with a mean programmatic diversity of 53 functions per hectare. Due to the much lower scale of development and more remote location, Drawn Study Three, Allerton Bywater – Scale of the Urban Grain, was not able to achieve diversity as high as that of Drawn Study One; the benchmark was assessed as 1.3 functions per hectare.

The remote location and relatively small scale of development means that the benchmark of Drawn Study 3 is a disparate result in terms of a value to establish the performance of the 'urban house in paradise'. Therefore it is not considered in terms of proposing a benchmark for this criterion, which is based upon the European comparative and Drawn Study 1. However, despite the fact that an exemplary comparative building was selected from a number of possibilities that were considered, this is a limited sample. Therefore it would be prudent, if the benchmarking process were to be extended, to validate this value with other precedents. A benchmark value has been selected for the 'urban house in paradise' that is closely comparable to the two values determined above, of 50 functions per hectare.

Methodology of Assessment

The quantification of the benchmark value of programmatic diversity is a measure of the number of functions within a defined area, which is the site of a new housing project. This can be summarised by the following equation:

Value of Diversity = Number of functions / Area of the site

Conclusion

Therefore, the proposed benchmark for the criterion of Diversity, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative

---

[4] The dwellings and offices are considered as one function; however, as the shops could be individual in terms of their clientele, they are considered individually.

and Drawn Study 1: Glasgow – Scale of the Urban Block, is proposed in the table below:

	Diversity (functions.ha^{-1})
Typical UK speculative dwelling	1
European comparative: Prisma	42
Drawn Study: 1	53
The 'urban house in paradise'	**50**

Diversity benchmark for the 'urban house in paradise'

3.11 Domestic Waste Recycling

Research by the Department of the Environment, Transport and the Regions, published in June 1997, states that 23.82 million tonnes of household waste was produced in England and Wales in the year 1995 to 1996; it is estimated that this value will increase on average by 3 percent per annum.[1] To put this another way, each household in the United Kingdom produces an average of over 1 tonne of waste per annum.[2] This is approximately 5 percent of the total annual waste arising in the United Kingdom.[3] The vast majority of this waste is disposed of through landfill, an 'out of sight, out of mind attitude' to waste management. Landfill sites produce leachate that can pollute ground water, and also produce methane which, kilogramme for kilogramme, is 70 times as potent as a greenhouse gas than carbon dioxide. Current attitudes to waste disposal, therefore, are not only problematic in terms of creating polluted holes in the ground; they also have a linear attitude to material use, in which natural resources are disposed of at the end of one lifecycle, which generates pollution and contributes to the greenhouse effect, and therefore global sea level rise.

To a great extent, at least at present, domestic waste recycling in the United Kingdom relies heavily on the proactive initiative of inhabitants to separate waste and take it to a local collection point themselves. Some local authorities, as demonstrated by Leeds City Council at Allerton Bywater, have a future plan of dual collection, with one receptacle for non-recyclable material and one for recyclable materials. Others, such as Bradford Metropolitan City Council, are in the trial stages of dual collection, also with one receptacle for non-recyclable material and one for recyclable materials.

The extent of separation of these materials may vary greatly; in areas of Germany; for example, seven or more receptacles are used to separate waste, by material type, prior to collection. This can be compared with the previously described example within the United Kingdom, where separation is carried out after collection and therefore only two receptacles are required. In either case there will be the need for storage within the dwelling for recyclable and non-recyclable materials. As the matrix of criteria that define the 'urban house in paradise' is not able to predict the future, the implications on space of the benchmarked level of domestic recycling in the context of different scenarios should be considered.

---

[1] 'Recycling Revolution', *Panorama*, BBC Television, 26 June 2000.
[2] Department of the Environment, Transport and the Regions. *A Better Quality of Life - A Strategy for Sustainable Development for the UK*, London: HMSO, May 1999.
[3] Madden, Pauline. *Sustainable Waste Management*, unpublished BSc Construction Management thesis, Liverpool John Moores University, 1997.

The benchmark value of reduction in domestic waste through recycling, and its consequent space provision, will depend also upon the proportions of recyclable waste within the average domestic weekly output. The Centre conducted research for the Biology of Natural Systems (CBNS) at Queens College of the City University of New York. A pilot project for domestic recycling was carried out to determine the percentage of domestic waste that could be recovered in marketable forms.[4] The waste collected was categorised under three headings: recyclable materials, compostable materials and non-recyclable materials. The actual figure of the waste recovered by composting and recycling was 84.4 percent of the original domestic waste.

The Allerton Bywater Millennium Community Competition Brief set a target of a 50 percent reduction in household waste, and to reduce landfill waste to near zero.[5] In the light of the CBNS research, although it may be a significant step forward from the current situation, a 50 percent reduction in domestic waste through recycling is not pushing the potential limits; a benchmark of innovative best practice should, therefore, reflect this.

Therefore, the benchmark value and space provision will be dependent upon the total waste produced each week, and the proportions of recyclable material that this is composed of. Research conducted on behalf of Merseyside Waste Disposal Authority, by AEA Technology, put forward the following as the waste composition of the typical dustbin waste in a largely urban area. This is summarised in the table overleaf. These figures confirm that more than seventy five percent of domestic waste is potentially recyclable.

---

[4] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998.
[5] English Partnerships, *Millennium Communities Competition - Allerton Bywater Stage Two Development Brief*, 1998.

Material	Percentage	Mass (kg.p^{-1}.wk^{-1})
Paper/card	31.9	3.0
Plastic film	4.9	0.5
Dense Plastic	5.3	0.5
Textiles	2.5	0.2
Miscellaneous combustibles	8.0	0.7
Miscellaneous non-combustibles	2.6	0.2
Glass	8.1	0.8
Putrescibles	20.7	1.9
Ferrous metal	5.6	0.5
Non-ferrous metal	1.3	0.1
<10mm fines	8.9	0.8
Total	100	9.3

Composition of weekly domestic waste for typical urban Merseyside dwelling[6]

The national average domestic waste production is approximately one tonne per household per annum, or approximately 19.2 kg per household per week. The research conducted on behalf of Merseyside Waste Disposal Authority showed that the region's 580,000 households produce approximately 380,000 tonnes of waste annually, or 25 kg per household per week. Work carried out under the National Household Waste Analysis Project, whose results were in line with the 1995 to 1996 Department of the Environment, Transport and the Regions municipal waste management survey, indicates that the introduction of wheeled bins increases the quantity of domestic waste by twenty percent, as a consequence of their increased capacity; this increase is largely attributed to garden waste.[7] This increase is demonstrated by the figure of the average production per week by Merseyside's households, where three of the five collection authorities use wheeled bins, which is slightly over twenty five percent above the national average.

In order to encourage domestic waste recycling, the *Environmental Standard* criteria call for a set of four containers, which are distinctly identifiable as being for different purposes, for example through colour, with a total capacity of, at minimum, 240 litres, or 0.24m^3 (the approximate capacity of a typical wheeled bin), per household. In addition, to be capable of accommodating additional waste receptacles in the future, a storage area of at least two

[6] Figures supplied by Merseyside Waste Disposal Authority.

square metres must be provided.[8] In areas of Leeds where dual collection is in progress, one of the two wheeled bins, with a capacity of 240 litres, is split into two compartments, one for organic and one for non-recyclable materials; a similar bin is provided for dry recyclable material. The town of Bury in Manchester has a similar process.[9] Whilst a project may not be capable of initiating a recycling programme, it should, as a minimum benchmark provision, provide the capability of storage for separated domestic waste into recyclable materials and non-recyclable refuse to be either collected or taken for collection from the dwelling. Therefore whilst the combined mass may remain fairly constant, the facility for waste storage must account for separation at the source, i.e. within the dwelling, or wherever the waste storage is located. It must also take into account that different locations may have different collection processes, in terms of the size, type and number of bins to be accommodated. If additional receptacles are to be provided for recyclable and compostable (putrescible) materials, as with wheeled bins the overall capacity will tend to increase, due to the combined capacity being above that of the traditional dustbin. This is confirmed by the proposed *Environmental Standard* figure for four receptacles, which is the same volume as a wheeled bin. Therefore, the base figure from which to calculate the benchmark of domestic waste reduction, through recycling, will also be affected by the twenty percent increase that wheeled bins create; as this is largely garden waste it will be compostable. The national average base figure is, therefore, 23.0 kg per household per week. This figure is then to be rationalised into a figure for the waste per person per week, to account for the diverse range of dwelling sizes that can constitute urban housing. Using the mean occupancy figure of 2.40 persons per dwelling[10] this equates to a national base figure of 9.6 kg per person per week.[11]

Research by the DETR, published in June 1997, suggests that of the 23.82 million tonnes of household waste produced in England and Wales in 1995 to 1996, 1.54 million tonnes, or 6.5 percent, was recycled.[12] 85 percent of the total was disposed of through landfill; the

[8] Prior, J. J. and Paul B. Bartlett. *Environmental Standard – Homes for a Greener World*, Garston: Building Research Establishment, 1995.
[9] Ibid.
[10] Office for National Statistics. *Living in Britain - Results from the 1995 General Household Survey*, London: HMSO, 1996.
[11] The criterion is also used in *EcoHomes*, the subsequent revision of the *Environmental Standard*, but not with such exacting requirements. Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.
[12] Department of the Environment. 'Authoritative Municipal Waste Statistics Released', press release, 9 June 1997.

remaining 8.5 percent was disposed through incineration, 3.5 percent with some form of heat recovery. With approximately 20,875,000 dwellings in England and Wales at that time, the 23.82 million tonnes equates to 1.1 tonnes per household per annum, or 21.9 kg per household per week, or 9.1 kg per person per week.

Whilst no benchmark will be capable of guaranteeing an influence upon the inhabitant's lifestyle habits, and cannot, therefore, ensure that inhabitants of dwelling adopt the practice of separating materials, it should at least benchmark the dwelling's provision and potential performance. Therefore, the proposed benchmark for the matrix will be the reduction of domestic waste by 75 percent of the standard weekly output, a factor four reduction, on the basis of the analysis presented above. In terms of the typical output level at present, this will equate to the reduction to the domestic refuse output of 2.4 kg per household per week, and a recyclable material output of 7.2 kg per household per week.

The method of storage and collection will be influenced, in the United Kingdom, by the individual local authorities, and therefore it is impossible to benchmark the provision of receptacles. However the spatial provision can be proposed, for which the *Environmental Standard* figure is adopted of, at minimum, 2 square metres of storage space per dwelling.

Methodology of Assessment

Compliance with the benchmark will be determined by at least the space provision for multiple receptacles for recyclable waste, of an area of 2.0 m^2. Large-scale projects should also include a strategy for the management of collection of sorted waste, such as that at Allerton Bywater.

Conclusion

Therefore, the comparable benchmarks for the level of domestic waste can be summarised as follows:

	Refuse	Recycled
Typical UK speculative dwelling	8.7	0.6
European comparative:	-	-
Drawn Study: 4	4.8	4.8
The 'urban house in paradise'	**2.4**	**7.2**

Recycling Domestic Waste benchmark for the 'urban house in paradise'

The storage area dedicated to separated waste will also form a part of the basis of the benchmark:

	Area for storage (m^2)
Typical UK speculative dwelling	0
European comparative:	-
Drawn Study: 4	0.24
The 'urban house in paradise'	**2.0**

Recycling Domestic Waste benchmark for the 'urban house in paradise', in terms of space provision

3.12 Ecological Significance of the Site

Whilst the thesis is predicated on urban housing, it should not be assumed that the land upon which the 'urban house in paradise' is constructed will therefore be of low ecological value. Also, following the Government's aspiration that 60 percent of the new dwellings required by 2016 are to be sited on brownfield, or previously developed, sites it should not be assumed that all brownfield sites are of low ecological significance. The re-use of previously developed land will assist in reducing or arresting the destruction of natural habitat and the biodiversity it supports. Indeed, green and ecologically rich spaces are crucial to the diversity that is one of the attributes of the urban environment. However, brownfield land may also have a hidden ecological value, particularly if it has been derelict for a period of time.

The Absolutely Constant Incontestably Stable Architectural Value Scale, developed by the American architect Malcolm Wells in the early 1970s, determined the impact of a building on the ecology of its site on the basis of its positive and detrimental effect on habitat and its effects on the natural resources of the site.[1] Wells' criteria were subsequently interpreted into a 'Matrix of Sustainability', published in 1992, by the American architect William McDonough. In terms of impact upon the site, McDonough's matrix valued a development in terms of the following criteria:

destroys rich soil	protects/creates rich soil
destroys nutrients	creates/adds nutrients
produces no food	produces food
destroys wildlife habitat	provides wildlife habitat
uses high productivity land	uses low productivity land[2]

The Building Research Establishment's *EcoHomes* assessment model also considers the ecological value of the site, in an attempt to,

> ... discourage building on ecologically valuable sites and to raise awareness of, to protect and to enhance local ecology.[3]

Credit is assigned for building on land that meets BREEAM's pre-determined criteria of low ecological value, which principally is land that has previously been built upon or is

[1] Wells, Malcolm. 'The Absolutely Constant Incontestably Stable Architectural Value Scale,' *Progressive Architecture*, March 1971.
[2] Cole, Raymond. J. 'Prioritising Environemntal Criteria in Building Design and Assessment,' from P. S. Brandon, P. L. Lombardi and V. Bentivgna. *Evaluation of the Built Environment for Sustainability*, London: E & F N Spon, 1997.
[3] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.
[4] Ibid.

contaminated. However, a derelict, demolished site may provide a habitat for important species. If the criteria of a low ecological site are not met, in order to achieve credit, a certificate must be obtained from the Royal Society for Nature Conservation (RSNC) confirming that the site is of low ecological significance. In the event that the site is of ecological value, confirmation must be made that the recommendations for minimising ecological damage will be undertaken. Additional credit from *EcoHomes* can be achieved through providing a "positive enhancement of the site ecology",[4] through recommendations from the RSNC.

The criteria used by *EcoHomes* to determine if land is of a low ecological is summarised below; only those applicable to an urban site have been included.

Type of land:

- Land which is entirely within the floor plan of a building demolished within the past 2 years.
- Land which is entirely covered by other constructions such as sporting facilities (hard surface tennis courts, or outdoor swimming pool) car parking or such constructions which have been demolished within the past 2 years.
- Land which is contaminated by industrial or other waste to the extent that it would need decontamination before building.

Ecological features:

- Is site devoid of trees or hedges above 1 m high?
- Are ponds, streams and rivers absent?

Provided that the land for the site falls into one of the three categories of type of land, and the questions on ecological features are all negative, then the land is considered to be of low ecological value.

The Canadian BEPAC environmental assessment method, which was created for the assessment of new and existing office buildings, assess the impact on the site in terms of the site use, water control on the site, and preservation of the landscape.

The United Kingdom Environmental Assessment system, which although unlikely to become a mandatory requirement for an urban housing project, does account for consideration to be made of the direct and indirect effects of the development on flora and fauna, soil, water and air. To some extent this could be considered as an account of the ecological value of the site, but it is more an analysis of the effects of the development on the ecology of the site, rather than an appraisal of its ecological significance.

In the 1996 Green Paper *Household Growth: Where Shall We Live?* The Government proposed that 60 percent of the new dwellings to be constructed by 2021 should be sited on brownfield, i.e. previously developed, sites. This value can should be seen in the context of the current balance between greenfield and brownfield land use for residential development in the United Kingdom, derived from the Urban Task Force report, which is approximately 53 and 47 percent.[5] Greenfield land is considered as a primary natural resource, and its use has implications, in anthropocentric terms, for material and energy use, and in deep ecological terms for biodiversity and hydrology.[6]

As the matrix of criteria that defines the 'urban house in paradise' is predicated on urban housing, the benchmark for brownfield land use should be above that of the Government's benchmark, which is concerned with all new housing construction. To minimise the consumption of natural resources, the ideal value for this benchmark would be that 100 percent of the site should be brownfield land. An analysis will also be undertaken, based on that of *EcoHomes* above, to ensure that the brownfield land is of a low ecological value.

Drawn Study 3, of the urban grain for the masterplan of the Millennium Community at Allerton Bywater was a former colliery site. It was chosen by the Department of the Environment, Transport and the Regions as a site for the competition because it demonstrated the development of a brownfield site. It was also contaminated, and had to be decontaminated and an 800 mm capping layer laid across the whole site.

In 1990 the IBA Emscher Park set out an ambitious programme to rehabilitate parts of the Ruhr. Half a century ago this was Germany's Black Country and centre for heavy industry, but is now an area of high unemployment and polluted wasteland. A housing competition was organised by IBA with emphasis on a green strategy both for a healthy environment and low energy use. The brief called for about 250 dwellings and other social facilities on a seven and a half hectare site on the edge of central Gelsenkirchen. The architects Szyszkowitz-Kowalski won the competition. The site itself had its own particular challenge in the form of the polluted soil, something which the Germans are more conscious about than many other countries in Europe. For this reason, the soil was removed to a depth of six metres and three

[5] Derived from Land Use Change Statistics in: Urban Task Force. *Towards an Urban Renaissance*, London: E & F N Spon, 1999.l

[6] Personal communication form Professor John Whitelegg, Professor of Environmental Studies, Liverpool John Moores University, 7 November 1999.

artificial hills were raised with imported soil. These hills provided, in part, the inspiration for Szyszkowitz-Kowalski's design.[7]

The organic design of the uHousing site layout followed the contour lines of the three hills, with a cranked line of dwellings, each with an inner core. This grouped the dwellings into three manageable batches, with a differing relationship to each other. The northern most enclave is half-open to the existing street, whilst the other two have urban sides containing retail units which engage with existing buildings. A man-made watercourse that runs diagonally through the site dissects the three enclaves, acting as the main spine. Water from the surrounding buildings is channeled via high level aqueducts, which deliver their contents via open chutes into the watercourse. The water flows into the main oval space, which becomes a temporary lake. Paths on either side of this waterway link all three enclaves, which act as focal meeting points with cafes and shops. Changes in level across the section are exploited, both with the central valley for the water and steps rising into the surrounding hills. This project demonstrates the innovative re-development of a heavily contaminated site, and the integration of the design into the process of decontamination.

Methodology of Assessment

The process of assessment that will be used to determine the performance of the dwelling against the benchmarks of the 'urban house in paradise', for each of its dimensions, is summarised below.

The site will be assessed to determine if it fulfils the Department of the Environment, Transport and the Regions' criteria for brownfield site compliance. To achieve the benchmark standard, the total site area must be compliant with the definition of brownfield land, which is summarised below, which is taken as that of previously developed land in Planning Policy Guidance Note Number 3 (PPG 3).[8]

> "Previously developed land is that which is or was occupied by a permanent structure, and associated fixed surface infrastructure. The definition covers the curtilage of the development...
>
> "The definition excludes land and buildings that are currently in use for agricultural or forestry purposes, and land in built-up areas which has not been developed previously (e.g. parks, recreation grounds, and allotments - even though these

[7] Architectural Review, Number 1214, April 1998.
[8] Department of the Environment, Transport and the Regions website, 4 May 2000:

areas may contain certain urban features such as paths, pavilions and other buildings). Also excluded is land that was previously developed but where the remains of any structure or activity have blended into the landscape in the process of time (to the extent that it can reasonably be considered as part of the natural surroundings), and where there is a clear reason that could outweigh the re-use of the site - such as its contribution to nature conservation - or it has subsequently been put to an amenity use and cannot be regarded as requiring redevelopment."

Once it has been established that the site is brownfield, it will then be assessed to ensure that it is also of a low ecological value. This methodology will be based on that used in *EcoHomes* to determine the compliance with its benchmarks. Therefore, the site should be able to be described by one of the descriptions of land type, and therefore answer 'yes, and should have none of the ecological features described, and therefore answer 'yes'.

Type of land:

- Is site composed of land that is entirely within the floor plan of a building demolished within the past 2 years?
- Is site composed of land that is entirely covered by other constructions such as sporting facilities (hard surface tennis courts, or outdoor swimming pool) car parking or such constructions which have been demolished within the past 2 years?
- Is site composed of land that is contaminated by industrial or other waste to the extent that it would need decontamination before building?

Ecological features:

- Is site devoid of tress or hedges above 1 m high?
- Are ponds, streams and rivers absent?

Conclusion

Therefore, the values for the Ecological Significance of the Site benchmarks of the 'urban house in paradise', seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative and Drawn Study Three, is proposed in the tables overleaf:

---

www.planning.detr.gov.uk/ppg3/9.htm,

	Proportion of site that is brownfield (%)
Typical UK speculative dwelling	47
European comparative: uHousing	100
Drawn Study: 3	100
The 'urban house in paradise'	**100**

Brownfield land benchmark for the 'urban house in paradise'

	Land Type	Ecological Features
Typical UK speculative dwelling	No	Unknown
European comparative: uHousing	Yes	Unknown
Drawn Study: 3	Yes	Yes
The 'urban house in paradise'	Yes	Yes

Ecological value benchmark for the 'urban house in paradise'

3.13 Ecological Weight: Embodied Energy

> I... discovered that *people did not talk about what a house weighed.* Nobody talked about having a beautiful little 350-ton cottage or a 700-ton Georgian job. That wasn't the language.[1]
>
> Richard Buckminster Fuller

For the influential and innovative American architect Richard Buckminster Fuller (1895-1983), the weight of a building became a critical consideration in the development of the industrialisation of housing production. A significant part of this preoccupation was of the inefficiency of the performance per unit weight of buildings when compared to other structures of a similar scale, such as ships. He demonstrated this with the comparison between the Hotel Belmont in New York City and the *Mauretania,* which had similar performance characteristics in terms of useable space per passenger and guest, and concluded that if the *Mauretania* weighed as much per unit of performance as the Belmot, she would have sunk on launching.[2]

The ecological weight is, in the spirit of Buckminster Fuller, a measure of the overall material efficiency for a dwelling; in other words, a measure of the overall embodied energy within the whole building, as opposed to a general measure of just the embodied energy per unit mass of the particular materials from which the dwelling is constructed. This will, therefore, account for materials with a low embodied energy level per unit mass, but that tend to be used in large quantities, such as concrete; also, conversely, lightweight materials with a high embodied energy per unit mass, but as they are lightweight, have a much larger volume per unit of energy. This assessment will also account for the, say, structural efficiency of the material itself. If a material has a slightly higher embodied energy per unit mass, but is significantly greater in terms of the efficiency with which it performs its role, it could be more efficient than a material which has a lower embodied energy per unit mass, but is required in greater quantity, leading to a lower cumulative level of embodied energy within the building as a whole. As proposed in the Conclusions, Chapter 12.0 in volume 1, the criterion could also be developed further than is considered here, to account for increased levels of mass, and therefore embodied energy, to create efficiency in energy consumption during inhabitation through high thermal mass.

In harmony with increasing the efficiency of dwellings is the reduction of the impact upon the

---

[1] Meller, James (ed). *The Buckminster Fuller Reader*, Jonathan Cape Ltd., 1970, p. 162.
[2] Ibid.

environment of their creation. The *ecological weight* benchmark will determine the level of the overall embodied energy of the 'urban house in paradise,' and a part of this calculation is the embodied energy of the materials from which the dwelling is constructed. The embodied energy of a material is defined as the energy consumed during the extraction, processing, manufacturing and fabrication, and transport during the period from when it is first wrenched from the ground to when it is delivered to the building site. It has been demonstrated that the embodied energy of construction materials typically accounts for 10 percent of the United Kingdom energy use.[3]

The embodied energy of a material, and consequent emissions arising from that energy expenditure, is only one of a range of factors that will affect the overall environmental impact of a material; others include the ecological degradation arising from extraction, depletion of resources, lifecycle and potential recyclability. Despite this complexity of other issues, the embodied energy value of a material will still give an indication of its overall level of sustainability. For example, the amount of energy expended in extracting a material will be proportional to the overall ecological impact that extraction has made. Also, the embodied energy of a material will be indicative of the emissions, such as CO_2, created by the extraction and processing of the material.[4]

> Most research has tended to confirm ... that the lower the level of processing needed in the production of materials, the lower the environmental impact.[5]

The British architectural scientist S. V. Szokolay has attempted to determined value for the embodied energy of a range of frequently used building materials, and categorised them into three levels of energy intensity.[6] This is summarised in the table overleaf.

[3] Connaughton, J. N. 'Real Low-Energy Buildings - The Energy Costs of Materials,' in Roaf, S. *Energy Efficiency*, Oxford: Oxford University Press, 1993.
[4] Vale, Brenda and Robert. *Green Architecture - Design for a Sustainable Future.* London: Thames and Hudson Limited, 1996.
[5] Smith, Maf, John Whitelegg and Nick Williams. *Greening the Built Environment*, London: Earthscan Limited, 1998.
[6] Szokolay, S. V. *Environmental Science Handbook*, London: The Construction Press, 1980.

Material	Energy Content (kWh.kg^{-1})
Low energy materials (<1 kWh.kg^{-1})	
Sand, gravel	0.01
Wood	0.1
Concrete	0.2
Sand-lime brickwork	0.4
Lightweight concrete	0.5
Medium energy materials (1-10 kWh.kg^{-1})	
Plasterboard	1.0
Brickwork	1.2
Lime	1.5
Cement	2.2
Rock wool	3.9
Glass	6.0
Porcelain	6.1
High energy materials (>10 kWh.kg^{-1})	
Plastics	10
Steel	10
Lead	14
Zinc	15
Copper	16
Aluminium	56

Embodied Energy of Common Building Materials[7]

It is important to consider that these values measure the embodied energy per unit mass, such as tonne or kilogramme, and that whilst materials such as aggregate and concrete, although having relatively low embodied energy levels per unit mass, are likely to be used in large quantities. Also, materials such as insulation, whilst having a relatively high embodied energy per unit mass, will have a large volume per unit mass, as opposed to, say, concrete. Therefore, the overall level of embodied energy used to insulate a dwelling may be lower than one might anticipate from simply comparing embodied energy levels per unit mass.

The Building Research Establishment has conducted research into the embodied energy used to produce building and construction products in the United Kingdom.[8] Analysis

[7] Ibid

[8] West, John, Carol Atkinson and Nigel Howard. 'Embodied Energy and Carbon Dioxide Emissions for Building Materials,' *Proceedings of the First International Conference - Buildings and the Environment*, CIB Task Group 8, Building Research Establishment, 16-20 May 1994.

indicated that the majority of energy consumed to produce building products was associated with the production of aggregates, cement, clay bricks, wood, glass, steel, plaster and plasterboard. The aim of the work was to update the embodied energy and associated CO_2 emission of these seven materials. Within the research, the embodied energy figures include an assumption of the energy consumed during the extraction and transport of raw materials, including imports, the energy consumption in processing and manufacture into material for direct use in construction, and the energy used to transport to site. The on-site processing and waste were factors that were not accounted for.

The *Green Building Digest* is a publication that specialises in the environmental impact of building materials; each edition is predicated on a particular component or element, such as glazing or roofing materials, and the environmental consequences of the different options for that element are analysed, in terms of, for example, their energy use, resource use, and their effects phenomena on global warming and acid rain.

The standard figures of embodied energy only account for the primary use of the building materials, and do not take into account recycling, where the embodied energy of the material will be a part of the lifecycle of the previous building, as 'extraction' will be through demolition or deconstruction. Research suggests that the energy embodied in recycled materials can be significantly less than that consumed in the processing of virgin ore; this is demonstrated in the table below.

Material	Energy Consumed in Processing. ($BTU.lb^{-1}$)		
	Virgin ore	Recycled material	% saved by recycling
Steel	8,300	4,400	47
Aluminium	134,700	5,000	96
Copper	25,900	2,150	92
Glass	7,800	7,200	8
Plastics	49,500	1,350	97
Newspaper	11,400	8,800	23

Energy consumed by virgin and recycled processing for common materials[9]

The following list presents a summary of the materials considered in the research by the Building Research Establishment, Szokolay and the *Green Building Digest*, in terms of their

[9] Hayes, D. Repairs, Reuse, 'Recycling – First Steps Toward A Sustainable Society', *Worldwatch Paper 23*, Washington: Worldwatch Institute, 1978.

embodied energy:

Material	Embodied energy (GJ.t^{-1})	Embodied CO_2 emission (kg.t^{-1})
Aggregates		
Natural crushed rock	0.5	37 (Transport only)
Fixed site recycled	0.4	30 "
On-site recycled	0.1	0 "
Sand and gravel	0.4	25 "
Cement		
Average	5.3	-
With pfa/ggbs	4.8	-
UK Clay Brick		
Continuous kiln Flettons	5.0	630
Cont. kiln non-Fletton commons	3.8	540
Cont. kiln facing and engineering	6.5	920
Intermittent kiln face and engin'ing	10	1,400
Timber		
Imported sawn softwood	7-9	600-1,000
Indigenous sawn softwood	5.7	710
Imported sawn hardwood	1-10	600-1,100
Indigenous sawn hardwood	5.7	710
Glass		
Flat glass	13	1,100
Glass fibre	30	2,500
Mineral Fibre	24	2,200
Plaster and Plasterboard		
Plaster	1.8	160
Plasterboard	2.7	240
Steel		
New strip	35	3,400
New section	32	3,200
Recycled strip	10	1,800
Recycled section	9	1,600
Other Metals		
Stainless steel	11	1,600
Aluminium	180 to 240	26,000 to 37,000
Aluminium (recycled)	10 to 18	-
Lead	190	16,000
Lead (recycled)	10	-
Copper	70	7,000
Copper (recycled)	10 to 60	1,000 to 6,000
Zinc	65	6,000
Roofing		
Clay tiles	6.3	-
Natural slate	<4	530 (not inc transport to site)
Concrete tile	1	-
Glass fibre felt	15-18	-
Plastics		
PVC	53 to 68	-
Polypropylene	100	
Polyethylene	85	

Indicative embodied energy and embodied CO_2 for building materials[10]

[10] West, John, Carol Atkinson and Nigel Howard. 'Embodied Energy and Carbon Dioxide Emissions for

From these figures, the value of the total ecological weight of the dwelling can be determined.

Szokolay, through the values of the embodied energy in materials, determined a value for the total embodied energy, or 'energy investment', of 1,000 $kWh.m^{-2}$ for typical domestic buildings.[11] As Szokolay goes on to explain, estimates of the energy content for a 100 m^2 two bedroom dwelling can vary considerably depending upon the construction method, and cites two examples. The first, of 50,000 kWh, or 500 $kWh.m^{-2}$, is for a timber frame single-storey dwelling, with a brick outer leaf, in Australia; the second, of 110,000 kWh, or 1,100 $kWh.m^{-2}$, is a brick two-storey dwelling in the United Kingdom. Although Szokolay does acknowledge that variations may have occurred due to climatic reasons and differences between methods of accounting for the embodied energy in materials, it is clear that the method of construction, and the efficiency with which construction utilises material resources, will have a significant impact upon the total level of embodied energy in a dwelling.

As the level of embodied energy in a material is also an indicator of the degree of pollution caused by the extraction and production of that material, and its overall sustainability, the level of the total embodied energy of a dwelling will be a good indicator of its ecological impact, or weight.

Research has been undertaken by the Building Research Establishment into the potential transfer of embodied energy values for materials into whole building scenarios, and the effect on the overall level of embodied energy in the building of varying the material specification.[12] Preliminary studies of standard designs for three bedroom dwellings in the United Kingdom indicate that potential savings of between 10 and 15 percent could be achieved through the specification of components or elements with a lower embodied energy. Translating these potential reductions into Szokolay's figure for the total energy investment of typical domestic buildings, of 1,000 $kWh.m^{-2}$, would produce a new benchmark for the ecological weight of 850 to 900 $kWh.m^{-2}$.

The Greenwich Millennium Village project established a benchmark reduction in embodied energy of 50 percent. This was translated, using baseline data of an elemental analysis of the standard specification for a residential unit, into a preliminary quantitative benchmark of

Building Materials'; Szokolay, S. V. Op. Cit.; *Green Building Digest*, various editions.
[11] Szokolay, S. V. Op. Cit.

214.4 gigajoules of energy for a 60.9 m^2 mid-floor apartment[13]. The reason for this translation was in order to create representative values for each target against which the actual performance of the dwellings can be measured. This value can be converted into units that can be compared with figures above. Measured per unit area, this would be 3.52 $GJ.m^{-2}$, or 977.9 $kWh.m^{-2}$. This figure is then used by the Greenwich Millennium Village team to determine if their embodied energy is achieving the reduction from a baseline benchmark. The GMV value is within 3 percent of the figure derived from Szokolay, which increases confidence in its value as a baseline benchmark; also, the GMV value is for a different dwelling type, a mid-floor apartment flat, to the Szokolay one, an individual low rise house, which increases confidence that the value can be related to different dwelling types. The benchmark that the GMV team propose, if they achieve a 50 percent reduction, would be 488.8 $kWh.m^{-2}$.

In terms of a standard of best practice, innovative projects have already achieved considerable savings in the level of energy embodied in new dwellings. Homes built for the Knightstone housing association achieved a 75 percent saving in embodied energy over conventional housing, through the use of low-mass construction and prudent specification.[14] Applying this reduction to the figure determined by Szokolay for the embodied energy of conventional housing would give a value of 250 $kWh.m^{-2}$.

The analysis of the dwelling, created in Drawn Study Four established that the Ecological Weight: Embodied Energy benchmark was 640.6 $kWh.m^{-2}$. This is below the typical value derived from the analysis of Szokolay, but significantly above that of the Greenwich Millennium Village's target derived from their *Draft Benchmarking Manual*. The high value for an innovative project is because the construction technology used intended to maximise the thermal mass of the dwelling, and hence used a significant quantity of concrete.

Methodology of Assessment

The embodied energy content of the dwelling can be determined by calculating total mass of each different material used to construct it, including at least all of the materials used to

[12] West, John, Carol Atkinson and Nigel Howard. 'Embodied Energy and Carbon Dioxide Emissions for Building Materials,' *Proceedings of the First International Conference - Buildings and the Environment*, CIB Task Group 8, Building Research Establishment, 16-20 May 1994.
[13] English Partnerships. *Greenwich Millennium Village: Draft Benchmarking Manuel: Energy, Water Consumption and Constructional Efficiency Targets (second draft)*, unpublished, 5 May 1999.
[14] Department of the Environment, transport and the Regions website, 16 September 1999: www.environment.detr.gov.uk/sustainable/construction.

create the external envelope and interior elements such as floors, stairs and finishes. This can be achieved using design drawings or a bill of quantities. The design drawings can be used to establish the overall volume of each material, and standard values of density used to convert these into the mass of material. If possible, account can be made for wastage of materials; this is typically around 10 percent, derived from the Recycling of Construction Waste Benchmark, refer to Annexe 3.28, which this value could be linked to. The mass of materials can then be multiplied by the standard values of embodied energy per unit mass given above. This will determine the overall value of embodied energy in the dwelling, which can then be divided by the internal floor area to establish a value in terms of $kWh.m^{-2}$.

Conclusion

Therefore, the proposed value of the benchmark of the Ecological Weight: Embodied Energy of the 'urban house in paradise', in the context of the comparative standards of the best practice comparative and the Drawn Study, can be summarised in the table below.

	Ecological weight ($kWh.m^{-2}$)
Typical UK speculative dwelling	1,000
European comparative: Knightstone	250
Drawn Study: 4	640.6
The 'urban house in paradise'	**250**

Ecological Weight: Embodied Energy benchmark for the 'urban house in paradise'

3.14 Ecological Weight: Embodied Carbon Dioxide

The burning of fossil fuels to provide the energy consumed in the construction of the dwelling will have consequential carbon dioxide emissions. For example, it is estimated that the energy consumption arising from the production of building materials accounts for approximately 8 percent of the United Kingdom's CO_2 emission, which in 1990 amounted to 579 $MtCO_2$.[1]

Under the Ecological Weight: Embodied Energy criterion a value derived by Szokolay, through the values of the embodied energy in materials, for the total embodied energy, or 'energy investment', in typical domestic buildings of 1,000 $kWh.m^{-2}$.[2] This value was substantiated, and demonstrated as appropriate to other dwelling types by cross-referencing it with other sources.

In terms of an ideal standard, innovative projects have already achieved considerable savings in the level of energy embodied in new dwellings. Homes built for the Knightstone housing association achieved a 75 percent reduction in embodied energy over conventional housing, through the use of low-mass construction and prudent specification.[3] Applying this reduction to the figure determined by Szokolay for the embodied energy of conventional housing would give a value of 250 $kWh.m^{-2}$.

These figures can be used to determine an approximate value of the carbon dioxide emissions arising as a consequence of the consumption of this energy. Different fuel types produce different levels of emission per kWh consumed; therefore, the value of CO_2 emission per unit of fuel consumed must reflect the different processes of construction. A mean value of emission for a typical of fuel types used during the construction of a dwelling can be derived from Howard;[4] this equates to a value of 0.36 $kgCO_2.kWh^{-1}$. Therefore, an approximate value of the emission arising from the energy embodied in the materials of the typical speculative built dwelling can be determined as 360 $kgCO_2.m^{-2}$.

It may be possible to determine a more accurate value for specific materials dependent upon the balance of fuels types used. This would require a detailed profile to be established for

---

[1] West, John, Carol Atkinson and Nigel Howard. 'Embodied Energy and Carbon Dioxide Emissions for Building Materials,' *Proceedings of the First International Conference - Buildings and the Environment*, CIB Task Group 8, Building Research Establishment, 16-20 May 1994.
[2] Szokolay, S. V. *Environmental Science Handbook*, London: The Construction Press, 1980.
[3] Department of the Environment, transport and the Regions website, 16 September 1999: www.environment.detr.gov.uk/sustainable/construction.
[4] Howard, Nigel. 'Energy in Balance,' *Building Services*, May 1991.

each material. Such work has been commenced by the Building Research Establishment, in terms of studying materials within factory production processes, which is held on a confidential database, and therefore access to this information was not possible.[5] Hence the calculation is based upon the mean value derived from Howard.

The benchmarks of this criterion are therefore based upon the benchmarks for the Ecological Weight: Embodied Energy criterion, refer to Annexe 3.13. The values are derived using the methodology described below.

Methodology of Assessment

As it has not been possible to determine a more accurate value for specific materials, which reflects the balance of fuels types used in the extraction, production and transportation of each, the assessment will have to be based upon the aforementioned constant derived from Howard. The benchmark is determined by multiplying the Ecological Weight: Embodied Energy benchmark by the general emission factor of 0.36 $kgCO_2.kWh^{-1}$.

This could be superseded with a more accurate analysis, accounting for the various emission factors of different materials once this data is established. The embodied energy would be calculated in the same manner, but then multiplied by the emission factor for each material. These would then be summed to provide a total for the dwelling, which would be divided by the total internal floor area to give a value in terms of $kgCO_2.m^{-2}$.

Conclusion

Therefore, the proposed value of the benchmark of the Ecological Weight: Embodied Carbon Dioxide of the 'urban house in paradise', in the context of the comparative standards of the best practice comparative and the Drawn Study, can be summarised in the table overleaf.

[5] Personal communication: Jane Anderson, Consultant, Centre for Sustainable Construction, Building Research Establishment, 13 January 2000.

	Ecological weight ($kgCO_2.m^{-2}$)
Typical UK speculative dwelling	360
European comparative: Knightstone	90
Drawn Study: 4	262.6
The 'urban house in paradise'	**90**

Ecological Weight: Embodied Carbon Dioxide benchmark for the 'urban house in paradise'

3.15 Energy Consumption: Construction Process

The energy consumed during the extraction, processing and delivery of materials to site, and the energy consumed during the period of inhabitation of the dwelling have been considered by criteria Ecological Weight: Embodied Energy and Energy Consumption: Inhabitation.[1] This benchmark is concerned with the energy that is consumed by construction processes whilst on site. The construction of buildings on site is virtually a process of the assembly of previously manufactured components or processed materials; traditionally this has been a labour intensive process. Both of these factors combine to create a construction process that, on site, is not energy intensive. The increasing drive toward standardisation and prefabrication proposed by the Construction Taskforce report would serve to preserve, or further, the nature of the construction site as a place of assembly.

Existing research has made estimates of the energy consumed during the period of construction on site. In the United Kingdom, this is 14 percent of the total construction embodied energy requirement,[2] and in the United States it is 17 percent.[3] Using the value of the average energy intensity of the construction of the typical dwelling proposed by Szokolay of 1,000 kWh.m^{-2}, the values above can be translated into approximate values of the average energy consumed on site during the construction of dwellings. Accepting a mean value, of 15 percent, will help to account for variations arising from differences in construction methods of other countries. This equates to a value of the energy embodied in construction process of the typical speculative built dwelling of 150 kWh.m^{-2}. Two approaches could be taken to determining the benchmark of energy consumed, and consequent CO_2 emitted, on site during the construction of the 'urban house in paradise.' One would be to propose a reduction of the 'typical' figure of CO_2. The other would be to translate the value proposed by the benchmark of Ecological Weight for the 'urban house in paradise' using the 15 percent mean determined above.

The Allerton Bywater Millennium Community Competition Brief set down targets of reducing the overall primary energy consumption in the construction and inhabitation of new dwellings by 80 percent.[4] Achieving this target could be made through combination of reducing the

[1] Refer to Annexes 3.13 and 3.16 respectively.
[2] Casper et al. *Energy Analysis of the Report on the Consensus of Production, 1968*, Open University Energy Research Group Report ER G006, 1975.
[3] Stein, R. G. et al. *Handbook of Energy Use in Construction*, US Department of Energy, 1981.
[4] English Partnerships. *Millennium Communities Competition - Allerton Bywater Stage Two Development Brief, September* 1998.

energy consumption both during the period of construction and during the period of inhabitation.

Benefit will be gained, in terms of reducing this criterion, through increasing the use of prefabrication in construction. The energy consumed on site will be minimal if the period on site is reduced, and the construction processes restricted to that of assembly. However, it should be ensured that any additional energy consumed in the production of prefabricated elements is accounted for in the Ecological Weight: Embodied Energy benchmark.

The Ecological Weight: Embodied Energy benchmark translated Szokolay's figure of the embodied energy of a typical dwelling into a benchmark of 250 $kWh.m^{-2}$ for the 'urban house in paradise'. Assuming that the same proportion of the total construction energy is consumed during construction on site, 15 percent, this equates to a figure of 37.5 $kWh.m^{-2}$. The consequent CO_2 emission from this can be approximated as 14.4 $kgCO_2.m^{-2}$. This value would demand a reduction in the energy used during construction on site of 75 percent, or put another way by a factor of four. In processes that have been identified above as not relatively energy intensive this could be perceived as too demanding. Therefore, it is proposed that this benchmark reduction will be 50 percent of the Szokolay value, or 75 $kWh.m^{-2}$.

It may be possible to determine a more accurate value for specific materials dependent upon the quantity of energy consumed by different construction processes. A breakdown of specific energy consumption rates by individual processes has not able to be determined. The Building Research Establishment has undertaken a significant amount of research on the embodied energy of construction after materials have been delivered to site; however this information is retained on a confidential database within the Centre for Sustainable Construction.[5]

The benchmarks of this criterion are therefore based upon the benchmarks for the Ecological Weight: Embodied Energy criterion, refer to Annexe 3.13. The values are derived using the methodology described about, basing the proportion of energy consumed on site as 15 percent of the total embodied energy of the dwelling.

Methodology of Assessment

As it has not been possible to determine a more accurate value for specific materials, which reflects the balance of fuels types consumed by different construction methods, the assessment will have to be based upon the aforementioned constant of 15 percent, derived from Stein, R. G. et al. The benchmark is determined by multiplying the Ecological Weight: Embodied Energy benchmark by a factor of 0.15. However, it is recognised that at very low embodied energies, reducing the consumption of processes that are not relatively intensive may prove too demanding.

This methodology could be superseded with a more accurate analysis, accounting for the different consumption by various construction methods if this data can be determined in the future. This would make the assessment more valuable in terms of assessing the different impacts of various construction methods, and the benefits of increasing prefabrication.

Conclusion

Therefore, the proposed value of the benchmark of the Energy Consumption: Construction Processes of the 'urban house in paradise', in the context of the comparative standards of the best practice comparative and the Drawn Study, can be summarised in the table below.

	Energy Consumption(kWh.m^{-2})
Typical UK speculative dwelling	150
European comparative: Knightstone	38
Drawn Study: 4	96.1
The 'urban house in paradise'	**75**

Energy Consumption: Construction Processes benchmark for the 'urban house in paradise'

[5] Personal communication with Suzy Edwards of the Sustainable Construction Unit at the Building Research Establishment, 5 October 1999.

3.16 Energy Consumption: Inhabitation

Energy consumption is a criterion that is dependent upon several other factors, some of which can be influenced through design, such as thermal performance, structural infiltration and orientation, others which cannot, such as the efficiency of appliances within the dwelling and the lifestyle of the inhabitants; therefore, some of these are within, but some might be considered beyond, the remit of the 'urban house in paradise'. Because it is affected by so many other criteria, yet is a critically important value in measuring the performance of the dwelling, it demonstrates the critical significance of interrelated structure of the matrix of benchmarks.

For the 'urban house in paradise,' the energy consumption of the dwelling during its life-cycle would be required to be a zero or negative value, achieved through energy generation by passive or active means, as a potential 'trade-off' against energy used during construction. This value will be affected, in turn, by the thermal performance of the fabric, or the level of the insulation, any passive or active energy generation, the efficiency of the services, and the effects of ventilation and structural infiltration upon the internal environment. It is also a criterion that has consequential effects on other criteria, such as the level of CO_2 emissions during inhabitation. This demonstrates the need to establish the best overall balance of priorities, which is achieved through the interrelated matrix of criteria.

Since 1970 the standards of energy efficiency of the United Kingdom Housing stock has steadily been increasing, both through retro-fitting more efficient appliances, services and insulation to existing dwellings, and through improving the standards demanded by new build. This increase in efficiency has, in the context of household growth, maintained the energy consumption by the domestic sector at a relatively constant level; or, to interpret it in a different way, at a level 30 percent below what it would have been had those efficiency methods not been undertaken.[1] However, the standards of new build can be pushed much further.

Robert Lowe and Malcolm Bell in their report to the Joseph Rowntree Foundation, *Toward Sustainable Housing: Building Regulation for the 21st Century,*[2] present a figure for the mean energy consumption of dwellings within the United Kingdom of 290 $kWh.m^{-2}.a^{-1}$. The

[1] Henderson, G. and L. D. Shorrock. *Energy Efficiency in the Housing Stock*, IP 22/88, Building Research Establishment, December 1998; and Dunster, J. E. and I. Michel and L. D. Shorrock. *Energy Use in Housing Stock*, IP 20/94, Building Research Establishment, December 1994.
[2] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.

level of energy consumption of a typical dwelling built in the United Kingdom to current Building Regulation standards[3] can be calculated using information from BRECSU's *General Information Report Number 53.*[4] This provides the energy consumption of the typical dwelling; from the space standards research conducted as a part of the thesis research, the latter source into energy consumption per unit area. The floor area of the 'typical dwelling' has been determined elsewhere in the thesis[5] as 84.2 m^2. This can be summarised in the following table. From this 'typical' figure the existing aspirational reductions, from sources such as the Millennium Communities competitions, can then be translated into quantitative benchmark values, and their level of innovation determined against current European best practice.

Function	Energy consumption		
	($kWh.a^{-1}$)	Percent	($kWh.m^{-2}.a^{-1}$)
Space Heating	7,926 (gas)	49	94
Hot water	4,548 (gas)	28	54
Pumps and fans	175 (electricity)	1	2
Cooking	656 (electricity)	4	8
Lights and Appliances	3,000 (electricity)	18	36
Total	**16,305**	**100**	194

Energy Consumption of a typical dwelling built to current Building Regulations[6]

The dwellings proposed for the first Millennium Community competition at Greenwich set the target of cutting the annual primary energy consumption of the dwellings by 80 percent of building regulation standards,[7] this would translate to a reduction to 36.6 $kWh.m^{-2}.a^{-1}$. The brief for the Allerton Bywater Millennium Community competition included the objective of a 50 percent reduction in energy consumption in comparison with conventional housing.[8] Taking the typical product of the house building industry for the basis of this reduction, this aspirational target translates to a benchmark value of energy consumption of 91.5 $kWh.m^{-2}.a^{-1}$. The dwellings designed for the Millennium Community competition at Allerton Bywater, constituting Drawn Study Four, were calculated to have a predicted energy consumption of

[3] It should be recognised that at the time of writing these Regulations are under review.
[4] BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, London: HMSO, October 1998.
[5] From space standards analysis. Refer to Anne 3.30.
[6] BRECSU. 'Building a Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, London: Construction Research Communications Limited, October 1998.
[7] Smit, Josephine. 'Sustainable Environment,' *Building Homes*, April 1998.
[8] English Partnerships. *Millennium Communities Competition - Allerton Bywater Stage Two Development Brief*, 1998, p.14.

15 kWh.m^{-2}.a^{-1} for space and water heating. This translates to a 90 percent reduction in comparison with the typical dwelling. These figures provide innovative, although achievable, standards of energy consumption for a dwelling, that can act as initial figures for developing a valued benchmark for the 'urban house in paradise'.

In 1983, Sweden adopted standards that made 50 to 60 kWh.m^{-2}.a^{-1} the maximum permissible heat loss for dwellings.[9] This value can also be interpreted as the energy consumption that is required to heat the dwelling to overcome this heat loss, which can be compared with the current typical space heating requirement of a dwelling in the United Kingdom of 94 kWh.m^{-2}.a^{-1}.

However, in terms of the philosophy of *Factor Four*, if the standard of living were to remain the same, then the level of energy consumption should be reduced by a factor of four, and therefore to 25 percent of its original value. This would create a benchmark value for the typical United Kingdom dwelling of 48.5 kWh.m^{-2}.a^{-1}, although *Factor Four* philosophy demands that building should be net exporters, rather than consumers, of energy. As has been proved by Drawn Study Four, 48.5 kWh.m^{-2}.a^{-1} is a viable figure for an energy consumption benchmark. However, further analysis would have to be undertaken to determine if this reduction is also being achieved with a factor four reduction of material and embodied energy consumption.

From the table above it can be seen that it is crucial to set an innovative benchmark for the energy consumption arising from space heating, as this can account for half of the total energy consumption of the typical dwelling. In addition, in conventional housing, the same appliance often supplies both the space and hot water heating demand, which can account for over three quarters of the total energy demand. Of course, in very high performance dwellings, with very high standards of thermal performance of the building fabric and glazing, the need for space heating, and its proportionate value in terms of other energy consumption functions, reduces. A exemplary precedent of this is Robert and Brenda Vale's Autonomous House in Southwell, refer to 5.2 in volume 1, in which space heating accounts for 4 of the 22 kWh.m^{-2}.a^{-1} consumption, or only 18 percent.

The energy consumption for the typical dwelling can also be viewed in comparison with the consumption levels presented in *GIR 53* for the 'zero CO_2' dwelling and the 'zero heating' dwelling. *GIR 53* also proposes values for the theoretical minimum energy use for an

[9] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998, p. 13.

table below.

Function	Energy consumption ($kWh.m^{-2}.a^{-1}$)			
	'Typical'	Zero CO_2	Zero Heating	Theoretical min
Space Heating	94	38	3	0
Hot water	54	28	20	8
Pumps and fans	2	-	2	1
Cooking	8	4	4	4
Lights and Appliances	36	32	25	12
Total	**194**	**96**	54	25

Comparable Energy Consumption of Typical and Low-Energy Dwellings[10]

In BRECSU's *General Information Report 39*, a detailed review of ten ultra-low-energy dwellings from within the United Kingdom, the benchmark level of total energy consumption for inclusion was set as follows:

> ... assuming a mixture of fossil fuels and electricity, of <100 $kWh.m^{-2}.a^{-1}$. It was noted that <60 $kWh.m^{-2}.a^{-1}$ for all-electric schemes would be equivalent, in primary energy terms, to 100 for schemes using gas for space/water heating and cooking.[11]

In BRECSU's *General Information Report Number 38*[12] a review of ultra-low-energy dwellings from the United Kingdom and overseas is made. Of the United Kingdom projects reviewed, only four of the ten achieved this benchmark; and only two, the Berm House in Gwent by Peter Carpenter (1987) and the Autonomous House in Southwell by the Vales (1993 - 22 $kWh.m^{-2}.a^{-1}$) use less than 50 $kWh.m^{-2}.a^{-1}$. The levels of energy consumption for these dwellings is summarised in the table overleaf:

[9] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998, p. 13.
[10] BRECSU. Op. Cit.
[11] BRECSU. 'Review of Ultra-Low-Energy Homes - Ten UK Profiles in Detail,' *General Information Report 39*, London: HMSO, March 1996, p. 56.
[12] BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, London: HMSO, February 1996.

Project	Energy Consumption (kWh.m^{-2}.a^{-1})	
	Space Heating	Total
Zero-Energy Houses, Wadensil, Switz'd	-	14
The Berm House, Gwent	0	~19
Duncan House, Victoria, Canada	1	-
Autonomous House, Southwell	4	22
Elmsett Ecological House, East Suffolk	-	25
Kings Cross Eco House, London	-	25
Zero-Energy House, St Gallen, Switz'd	9	-
Passiv Haus, Darmstadt, Germany	10	32
Low-Energy Urban Housing, Netherlands	10	-
Low-Energy House B, Hjortekaer, Denmark	-	42
Waterloo Region Green Home, Ontario,Can	-	51
Denmark IEA Task 13, Copenhagen, Den'k	15	<60
Lower Watts House, Oxfordshire	-	65
Low-Energy House G, Hjortekaer, Denmark	20	70
Strawberry Hill Low-Energy Houses, Salford	30	-
Green Street, Ebbw Vale	47	78
Longwood House, Huddersfield	-	80
Mill Orchard, Herefordshire	-	80
The Cowe House, Boston, Lincolnshire	-	80
Warmhome 200, Newtonabbey, N. Ireland	45	81
Auton Croft, Saffron Walden	13	87
Ash Tree Cottage, Buckinghamshire	-	98
Crickhowell Tele-Village, Powys	30	70-100

Comparative Table of Energy Consumption of Low-Energy Dwellings[13]

The upper levels of performance of these examples provide an indication of what best practice is achieving in terms of energy consumption, and it is these that will inform the final value determined for the benchmark of energy consumption for the 'urban house in paradise.'

Factor Four demonstrates the potential reduction in energy consumption in dwellings

[13] BRECSU, *General Information Report 38*. Note: the 'Total' figure includes space and water heating, ventilation, lighting, appliances and cooking.

through the Passiv Haus project in Darmstadt, Germany,[14] a row of four terraced dwellings. The measured energy use of the Passiv Haus in 1992-3 was 32 $kWh.m^{-2}.a^{-1}$. Through exploiting passive solar energy generation, with almost no active heating, highly efficient glazing and insulation standards, $U_{wall} = 0.14$ $W.\ m^{-2}.K^{-1}$ and $U_{roof} = 0.09$ $W.\ m^{-2}.K^{-1}$, the auxiliary space heating demand was reduced to a level of 10 $kWh.m^{-2}.a^{-1}$.[15]

A value for the energy consumption of space heating only of 10 $kWh.m^{-2}.a^{-1}$ has been proven as a viable, achievable target in two existing projects, both appropriate to urban locations. The Passiv Haus project, and the Low-Energy Urban Housing development in Amsterdam, the Netherlands (1995) which is an apartment block building comprised of sixteen flats. In terms of generic benchmarks, such as the matrix will propose, it is important that the values proposed are appropriate to different types of building, and, in the case of the thesis, types of urban buildings. This can be demonstrated by the criterion of heat loss, which can vary between different dwelling types, such as terraced units or apartment flats.[16] However, these two examples demonstrate that the space heating demand, which is proportional to heat loss, can be a constant benchmark between different urban dwelling types.

In the Netherlands, a method has been developed to verify the calculated energy consumption of a dwelling against a permitted maximum; set by the Dutch Ministry of Housing, Physical Planning and the Environment, and termed Energy Performance Standardisation (EPN); the method was introduced in 1995. New dwellings now have to meet an energy performance standard for space heating, domestic hot water, and supplementary energy for heating and ventilation.[17]

Another example of best practice as opposed to standard practice is demonstrated by the following, which provide another reference from which to draw the benchmark of the energy consumption of the 'urban house in paradise'. This makes a comparison between the standard of a typical German dwelling built to current standards, and the innovative dwellings built as a part of the Expo 2000 project in Hanover. The project is for 142 low-rise flats for 500 inhabitants; all designs were to demonstrate that the energy consumption would not exceed 50 $kWh.m^{-2}.a^{-1}$. The modeling of the development established an estimated annual

[14] Weizsacker, Ernst Von, Amory B. Lovins and L. Hunter Lovins. Op. Cit., p. 13-15.
[15] Olivier, David and John Willoughby. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, HMSO, 1996.
[16] Baldwin, R. and G. Atkinson. *Investing in Energy Efficiency: 3 New Housing*, IP 22/86, Building research Establishment, December 1986.
[17] Anink, David, Chiel Boonstra and John Mak. Op. Cit.

energy demand of 49.8 $kWh.m^{-2}.a^{-1}$.[18] This value can be compared with the German equivalent built to current regulations, of 120 $kWh.m^{-2}.a^{-1}$.[19]

The predication of the thesis toward urban housing could have an impact upon the likely energy consumption of dwellings. Research has demonstrated that the energy consumption of dwelling types more prevalent in urban areas consume less energy than those more typical of greenfield housing. For example, it was shown that increasing the length of terraces of dwellings by between four and eight could reduce the overall energy demand by 10 percent. Form and proportion also have an impact; it was demonstrated that varying the frontage within the limits of normal medium frontage dwellings, compared with typical two storey dwellings could result in a reduction of the overall energy demand by 10 percent.[20]

The Greenwich Millennium Village project established a benchmark reduction in primary energy consumption of 80 percent. In order that comparisons could be made between traditional practice and the new standards of Greenwich, this was translated into a preliminary quantitative benchmark of 11,637 $kWh.m^{-2}.a^{-1}$ for a 60.9 m^2 mid-floor apartment.[21] This value gives the Greenwich Millennium Village team a typical value of the standard practice of the housing construction industry against which to assess the performance of their dwellings. The GMV value of energy consumption can be converted into one of consumption per unit area, this would be 191.1 $kWh.m^{-2}.a^{-1}$. This value is within two percent of the value determined, by the research above, as the typical value of energy consumption in dwelling in the United Kingdom, and gives confidence that the benchmark can be used for different dwelling types.

Another interrelated effect on energy consumption will be the space standards criterion. If the area of a dwelling is, for example, benchmarked to be increased by 3.7 m^2 per occupant, as the energy consumption benchmark is quantified by area, as it is measured in $kWh.m^{-2}.a^{-1}$, it will have a consequential effect on the total energy consumption of that dwelling. In terms of a *Factor Four* reduction in resource use, it would go against the grain of the philosophy of Factor Four if the reduction of energy consumption by a factor of four were not over and above that of the value of the increase in space standards.

---

[18] Bellew, Patrick and Jochen Kauschmann. 'Hanover Fare', *Building Services Journal*, August 2000.
[19] Aire Regeneration Partnership, *Annexes to the Report*, unpublished submission document for the Allerton Bywater Millennium Community competition, February 1999.
[20] Berry, J. et al. 'Conservation of Energy in Housing', *Building Services Engineer*, Volume 45 May 1977; and Longmore, J. and J. Musgrove. 'Urban Form and Energy Use', paper presented to the International Congress on Building Energy Management, Povoa de Varzim, Portugal, May 1980.
[21] English Partnerships. *Greenwich Millennium Village: Draft Benchmarking Manuel: Energy, Water Consumption and Constructional Efficiency Targets (second draft)*, unpublished, 5 May 1999.

Methodology of Assessment

Clearly, for the purposes of comparability a like-for-like methodology must be used in determining the energy consumption of dwellings for comparison against the benchmark of the 'urban house in paradise'. One method of determining the energy consumption level of a dwelling for comparison with the benchmark is using the Department of the Environment, Transport and the Regions' *Standard Assessment Procedure for Energy Rating of Dwellings*, the SAP rating.[22] This is the Government's standard system of rating the energy efficiency of a dwelling. In this respect it has the advantage that whether new build, or created by a change of use in refurbishment, it is a requirement of Building Regulations that dwelling must be given a SAP rating.[23] Therefore, little additional work would be required to determine how any new dwelling performs against the benchmark value.

Determining the value of the energy consumption requires the translation of one of the values determined in the SAP calculation, this value is the 'useful energy requirement' at step 81. By using a constant for converting the units of magnitude and the internal floor area of the dwelling, the value of the useful energy requirement, measured in units of $GJ.a^{-1}$, can be translated into a value of the energy consumption for the dwelling in $kWh.m^{-2}.a^{-1}$. This is how the value of energy consumption for Drawn Study Five was determined.

An additional advantage of using the SAP calculation process as a part of the assessment methodology is that the procedure includes an optional calculation to determine the CO_2 emission figure for the dwelling, on the basis of the energy consumed. This provides a quick and efficient way in which to determine the performance of the dwelling being considered against the CO_2 emission benchmark also.

However, there are disadvantages to the use of the SAP rating to determine the overall energy consumption of a dwelling. Whilst the calculation of the rating does take account of internal heat gains, such as lights, appliances, cooking and metabolic gains from the occupants, its takes no account of the energy consumption of lights, appliances and cooking. It only determines the overall energy consumption of the space and water heating systems. Therefore, it does not provide a holistic view of the overall energy consumption of the dwelling. This, of course, also means that the CO_2 calculation only reflects emissions from these sources also.

---

[22] Department of the Environment, Transport and the Regions. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, London: Construction Research Communications Limited, 1998.

Lowe and Bell identify an additional disadvantage to the SAP rating method. They suggest that as the SAP rating is based upon energy prices, the significance of the actual energy consumption and CO_2 emission levels are obscured. If the dwelling changes to a less expensive fuel type, and Lowe and Bell use the example of off-peak and on-peak electricity, the SAP rating increase, which will make the dwelling appear more efficient. They also point out that both the BREEAM *Environmental Standard* rating of dwellings, and the Danish building regulation base their valuation on the actual energy consumption and emission per unit of floor area, which is much more transparent, and more meaningful in terms of sustainability. However if, as described above, the SAP method is only used up to step 81, then the steps involving the energy cost calculation, and therefore the shortcomings identified by Lowe and Bell, can be avoided

The worksheet calculation of the SAP rating, first published in 1993, was developed from the Building Research Establishment's Domestic Energy Model (BREDEM). Several versions of BREDEM have been issued, in a number of standardised models of varying complexity, since its first publication in 1981.[24] The most recent versions are BREDEM-8, which is used to determine energy use on a month by month basis, and BREDEM-12, which measures annual consumption. Both of these models are not available as worksheet calculations, to determine the value of energy consumption by hand, but due to their complexity exist as computer programmes.

An advantage of the BREDEM value of energy consumption over the SAP value is that is does take account of the energy consumption of cookers, other appliances and lighting as a value of auxiliary fuel use based on floor area. As outlined above, it is important to consider that whereas the proportion of the energy consumed by space and water heating is the significant majority of the total energy consumption in a typical new dwelling, 77 percent in the table above, in low energy dwellings this is not the case. Where the space heating requirement is cut dramatically the proportional consumption of the total energy demand by the various functions is radically changed; therefore a significant proportion of the total energy consumption in a low energy dwelling can be attributed to appliances and lighting. For example, in the typical new build dwelling in the United Kingdom, built to current Regulations, the energy consumed by space heating accounts for 49 percent of the total energy consumption. However, in the Passiv Haus in Darmstadt, the space heating

[23] Department of the Environment and The Welsh Office. *The Building Regulations - 1995 Edition. Approved Document L - Conservation of Fuel and Power*, London: HMSO, 1995.
[24] L. D. Shorrock and B. R. Anderson. *A Guide to the Development of BREDEM*, IP 4/95, Building Research Establishment, February 1995.

accounts for 31 percent of the total energy use,[25] and at the Vale's Autonomous House in Southwell, space heating energy use accounts for only 18 percent of the total energy consumption.

An alternative methodology to assess the benchmark would be to use the SAP rating method to determine the energy consumption of the space and water heating systems, as affected by internal gains, and to use another source to determine the likely consumption of energy from lighting and appliances. Once such source of information on the consumption of domestic lights and appliances is produced by the Domestic Equipment and Carbon Dioxide Emission (DECADE) project, by the University of Oxford.[26] Another way in which to achieve this would be to adapt the relevant steps that account for the energy consumption of lights, cooking and appliances from the worksheet version of BREDEM into an assessment based on the SAP worksheet. As both of these worksheets have been developed in parallel, there can be considered to be comparability in their methodologies. Therefore this will constitute the way in which a dwelling will be assessed against the Energy Consumption: Inhabitation benchmark of the 'urban house in paradise'.

Conclusion

The comparative values of the overall energy consumption of dwellings, of the typical dwelling built in the United Kingdom to current Building Regulation standards, a European comparative, Drawn Study 5, and the 'urban house in paradise,' is summarised in the table overleaf. The sources through which the values have been derived are also included. Based on the evaluation above, innovating upon the comparative dwelling of European best practice within technical feasibility, the Energy Consumption: Inhabitation benchmark proposed for the 'urban house in paradise' will be 25 $kWh.m^{-2}.a^{-1}$.

[25] BRECSU. Op. Cit.
[26] Boardman, B. et al. *DECADE - Domestic Equipment and Carbon Dioxide Emissions. Second Year Report*, Environmental Change Unit, University of Oxford, 1995.
[27] BRECSU. *General Information Report 38.*

Function	Energy consumption ($kWh.m^{-2}.a^{-1}$)			
	Typical	Passiv Haus	Drawn Study 5	'u h in p'
Space heating	94	10[27]	15	12
Hot water	54	-	inc above	inc above
Pumps and Fans	2	-	3.7[28]	3[29]
Cooking	8	-	4[30]	3[31]
Lights and Appliance	36	-	12[32]	7[33]
Total	194	32	**35**	**25**

Energy Consumption: Inhabitation benchmark for the 'urban house in paradise'

[28] This value was calculated using the SAP worksheet for dwellings with mechanical ventilation.
[29] BRECSU. *General Information Report 53*
[30] Ibid.
[31] Ibid.
[32] Ibid.
[33] Ibid.

3.17 Energy Generation: Inhabitation

An autonomous dwelling, as defined by BRECSU's *General Information Report Number 53*,[1] must satisfy all of its energy demands through on-site, renewable energy generation, as either an isolated system or linked into the electricity grid. In the case of the latter, it must be a net exporter of sufficient renewably generated electricity from its own system to balance its consumption from the grid.[2] This will account for periods in which the dwelling is unable to generate sufficient renewable energy to fulfil its consumption demands, such as during the night if the source is photovoltaic panels, for which it will use the grid to make up the shortfall. During periods of excess generation, when the renewable sources are producing more energy than the dwelling is consuming, the excess energy is put into the grid. The justification behind this approach is that although the dwelling will, for certain periods, be consuming energy provided by fossil fuels, and with consequent CO_2 emissions, during the periods of excess generation the dwelling acts as a renewable source for the grid, supplying non-fossil fuel energy for consumption elsewhere. *Factor Four* proposes that buildings should be net exporters of energy.[3]

Through generating its own energy through renewable, natural sources, the dwelling can eliminate its reliance upon fossil fuel consumption during the period of inhabitation. This would both eradicate the consumption of a finite resource and the emissions of greenhouse gases such as CO_2 and nitrous oxides, and other pollutants.

Energy generation using solar sources, one of the most suitable sources of renewable energy for architecture, can be both passive and active. Passive generation is typically achieved by solar gain through areas of glazing; active generation includes the use of solar panels to heat water to be used directly or indirectly in the dwelling, or photovoltaic panels used as a power source. Other sources include wind power from turbines, geothermal heat from the earth and solar water panels for domestic hot water.[4]

If a dwelling were to be autonomous, and generate all of its own energy, then gas might be considered not a viable fuel source as its consumption cannot be directly counteracted by renewable generation. This has disadvantages in that it is one of the most efficient fuel

---

[1] BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, London: HMSO, October 1998.
[2] Ibid.
[3] Weizsacker, Ernst von, Amory B. Lovins and L. Hunter Lovins. *Factor Four - Doubling Wealth, Halving Resource Use*. London: Earthscan, 1998.
[4] Department of Trade and Industry 'New and Renewable Energy Programme' website, 19 April 2000: www.dti.gov.uk/renewable/

sources, and also has on of the lowest consequent CO_2 emission factors. Therefore, any electricity consumed by the dwelling from the grid should be generated using renewable sources, and thereby not contributing to CO_2 emissions. This can be achieved through the use of a 'green tariff.'[5] However, the use of gas could be justified provided that the total generation exceeds the level of consumption, including gas, as the national generation of electricity includes increasing numbers of gas-fired power stations, and therefore the use of mains electricity will still result in the depletion of natural gas. Therefore the demand is that the total generation exceeds consumption, irrespective of the types of fuel used in consumption.

The Energy Generation: Inhabitation benchmark will be related to the benchmark of Energy Consumption: Inhabitation; it will affect and be affected by the levels of consumption proposed for each function, and the contribution to that level that can be expected from renewable, on-site generated sources. For example, the space heating consumption level will be affected by the potential contribution of solar gain; and the level of consumption by lighting and appliances will be affect the demand on generated electricity.

Therefore, one needs to determine the heating demand level for the dwelling, which is contained within the total energy consumption benchmark for the period of inhabitation, and then determine what reduction should be contributed to by renewable sources, such as passive solar gain, biomass, geothermal and active solar generation. In terms of passive solar gain, this level of solar gain will be dependent upon factors such as the area of glazing, type of glazing and orientation.

Brenda and Robert Vale, who are the authors of *GIR 53*, referred to above, were also the architects for the Hockerton housing project in Southwell, Nottinghamshire.[6] This terrace of five dwellings, completed in 1998, is almost hidden by the earth berm into which it is set. Pending a planning appeal, a wind turbine is to be erected, which will mean that the development will generate its own energy, therefore causing no pollution or CO_2 emissions. An early value of the energy consumption measured after completion was 8 kWh per day,[7] which provides a benchmark for energy generation if the dwellings are to be autonomous.

However, the generation of renewable energy need not be considered in terms of the scale

---

[5] BRESCU, Op. Cit.

[6] BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, London: HMSO, February 1996.

[7] Smit, Josephine. 'Underground, Overground, CO_2 Free', *Building Homes*, October 1998.

of an individual dwelling. Micropower is the generation of energy within networks of small-scale, decentralised power plants,[8] with local generation providing for local consumption. The advantages of this system is that transmission losses are lower, and the excess heat from generation can be used for space and water heating within buildings, like combined heat and power systems. Microgeneration also tends to be more environmentally benign, with American systems being powered by hydrogen, and solar power. It is envisaged by some that the evolving technology of fuel cells, particularly in America, will further contribute to the advantages of mirogeneration; the only byproducts of fuel cells are water and oxygen. The Vales also advocate the use of localised generation,[9] through its increased contribution to autonomy. The small-scale, autonomous generation of micropower seems particularly pertinent to large-scale urban projects, where a localised source of generation could provide sufficient energy for all dwellings within the project.

As stated above, the benchmark for the generation of energy within the dwelling will be directly related to the Energy Consumption: Inhabitation benchmark, which it should be at least equivalent to, or exceed, if the dwelling is to be considered 'autonomous'. Thereby, the dwelling will become zero net energy consuming, and will contribute zero net CO_2 emissions; should the level of generation exceed consumption, it will also fulfill the *Factor Four* aspiration of being a net provider of energy. For example, if the dwelling achieves the Energy Consumption: Inhabitation benchmark of the 'urban house in paradise' of 25 $kWh.m^{-2}.a^{-1}$, then the Energy Generation: Inhabitation benchmark will at least 25 $kWh.m^{-2}.a^{-1}$.

In Southwell he Vales have attempted to create a dwelling that, as far as possible, can be serviced through the natural resources that fall upon its site. The principal philosophy used, in respect to sustainability, in the design of their dwelling is autonomy in all services. In terms of renewable energy generation, a 2.2 kW photovoltaic array, composed of 36 panels that are connected to the national electricity grid through an inverter, is sited on a pergola in the garden. The decision to connect the system to the mains, to create a 'trade-off' between supplying excess energy to the grid when generation exceeded consumption and drawing from it when consumption exceeds generation, was taken in favour of using a form of storage, most commonly batteries. This was based on the view that as the grid is already in existence, its embodied impact has been made, whereas the embodied impacts of batteries, including resource consumption and potential pollution due to their lead content, would be

[8] Anon. 'The Dawn of Micropower', *The Economist*, 5 August 2000.
[9] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.

new. Other implications included higher costs, and the additional space required to store the batteries, which can pose hazards such as fire and explosion.[10]

The Southwell dwelling demonstrates that, at least theoretically, it is feasible to meet the benchmark of balancing energy consumption and generation, although in reality the dwelling did not achieve this. The energy consumption of the dwelling has been measured as 22.9 $kWh.m^{-2}.a^{-1}$, including 5.2 $kWh.m^{-2}.a^{-1}$ of wood; the photovoltaic array generates 9.2 $kWh.m^{-2}.a^{-1}$, a deficit of 13.7 $kWh.m^{-2}.a^{-1}$. It has been calculated by the Vales that reducing the energy consumption further, principally through installing a heat pump to replace the immersion water heater and increasing the insulation to the water tank, and adding to the number of photovoltaic panels will achieve an energy balance.[11] However, achieving this has demanded a significant reduction in the energy demands made by space and water heating, lighting and appliances.

As has been proposed, the energy consumption of the dwelling will be determined through the SAP model. The renewable generation of 25 $kWh.m^{-2}.a^{-1}$ may well be a technically feasible proposal within an urban context. However, if the quantity of energy consumption were to rise to the values typical of that of dwellings constructed to current regulation standards, then this is unlikely to be the case. Therefore, the designer must be aware of the importance in achieving the Energy Consumption: Inhabitation benchmark, in order to achieve that of Energy Generation: Inhabitation also.

Methodology of Assessment

The benchmark has been established that the energy generated by the dwelling should equal or exceed the energy that is consumed by it. A number of methods are proposed for assessing the contribution from the variety of renewable energy sources that might be utilised by the 'urban house in paradise'.

Solar Water Panels. The SAP assessment already includes steps in which to determine the contribution of solar water panels to the energy consumption of the dwelling. Therefore these steps, 44 to 47, can be used to determine the quantity of energy available from solar water panels, depending upon the area available.

[10] Ibid.
[11] Ibid.

Photovoltaic Panels. The energy that is available from photovoltaic panels will be dependent upon the energy that is available on the site from the sun, the efficiency of the panels, or modules, and the area of the array. The energy that is available from the sun can be determined on a daily or annual basis. In the former case, the value of kilowatt-hours peak per day, typically 3 to 4, is multiplied by 365.25 to determine the mean availability per annum. Alternatively, data for the mean annual energy available for a variety of locations, which is typically 1 $kW.m^{-2}$ for 1,000 hours each year, therefore 1,000 $kWh.m^{-2}.a^{-1}$, can be used to determine the energy available on the basis of the area of panels available. The actual energy that will be provided by the panels will be dependent upon their efficiency; a typical value of which is 18 or 19 percent;[12] therefore on average only 18 to 19 percent of the energy that is available will be converted into electricity. Multiplying the energy available by the efficiency of the panel, as a decimal out of one, will determine the electrical energy available per unit area; multiplying this by the area of the array will provide a total value for the mean annual energy that is available from photovoltaic generation.

Wind Turbines. The energy generation that could be made by wind turbines is particularised through meteorological data for the average monthly wind velocity at the location of the turbine.[13] As this data is typically taken at a height of 10 metres, the value should then be amended to account for the difference between the velocity at 10 metres and the velocity at the hub height of the turbine, which should be based on the manufacturer's specification for the particular turbine. The morphology of the land surrounding the turbine will also affect the wind velocity; the roughness length accounts for this. The energy yield for each turbine is then interpolated on manufacturer's data for the turbine, and multiplied by the total number of turbines.

Conclusion

To be compliant with the 'urban house in paradise', the benchmark value will be at least an equal value to the Energy Consumption: Inhabitation benchmark. This can be summarised in the expression below.

Energy Generation: Inhabitation ≥ Energy Consumption: Inhabitation value.

Therefore, the quantitative value will be dependent upon the overall energy consumption of the dwelling. For this reason, the benchmark is proposed in two parts. The first is based

[12] Roaf, Dr Susan. Lecturing at 'Sustainability in Building Design' seminar, University College, Chester, on 18 August 1999.

[13] The energy generation by wind turbines is determined through a calculation method used by the Centre for Alternative Technology, Machynlleth; personal communication November 1995.

upon the energy generation requirement if the Energy Consumption: Inhabitation benchmark is achieved; the second part will qualify the demand if it is not. Therefore, the proposed benchmark for the criterion, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative and Drawn Study Four, is proposed in the table below:

	Energy Generation ($kWh.m^{-2}.a^{-1}$)
Typical UK speculative dwelling	0
European comparative: Southwell	9.2
Drawn Study: 5	0
The 'urban house in paradise'	**25, or ≥ Energy Consumption**

Energy Generation: Inhabitation benchmark for the 'urban house in paradise'

3.18 Green Space

The provision of green space as a benchmark within the matrix of criteria that define the 'urban house in paradise' will be to fulfil two aims. The first will be to improve the ecological value of the site through increasing the species diversity, and the second is to provide space that can be used for the assimilation of CO_2, which is absorbed by plant life. Open space will also provide spatial counterpoint to built form, which is particularly relevant in the context of increasing residential density; net density does not include the provision of strategic open space. An additional potential advantage is the production of food, in winter gardens or allotments, to reduce the import of goods into the city. An additional potential advantage is the production of food, in winter gardens or allotments, to reduce the import of goods into the city. *Factor Four* expresses the notion that all buildings should be net exporters of food, in addition to energy and beauty.[1]

Biodiversity is one of the fundamental demands of the natural environment. Yet whilst green space may provide diversity through counterpoint in the urban fabric, species variety and diversity is something that is frequently absent from urban green space. Hough contrasts two urban environments: firstly a green, formally landscaped boulevard in a city centre, which is comprised of four or five species of plants and which supports no wildlife, and secondly an abandoned waterfront site, which supports over 400 species of plants and frequented by 290 species of birds. He then asks the question, which should be considered the derelict site?[2]

Whilst not all urban sites can expect to attract the diversity found on abandoned waterfronts, Hough makes the important point that the values that have determined the image of nature within the city should be questioned. Rather than aesthetic value, perhaps consideration should be given to enhancing the diversity of species within new green space as opposed to reducing it, which is the effect that the traditional imposition of a formal city landscape over the original has had upon natural biodiversity.

In the revisions considered for the most recent version of the assessment *EcoHomes*, credit is awarded for improving the ecological significance of the site. An evaluation of the biodiversity of the site is made before and after development, using natural plant species as a proxy for the overall ecological diversity. Credit is then awarded on the basis of the degree of improvement to natural biodiversity.

---

[1] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998.

It should be recognised that there will be an interrelated link between the criterion of the provision of green space and that of Density: Quantitative, refer to Annexe 3.8. This can be demonstrated through the parameters that are use in the assessment of net residential density, which includes private garden space and incidental open space and landscaping. Therefore if an increase in the area of green space is proposed, this will have a consequential impact of decreasing the net residential density of the project.

Historically, an assured food supply was the foundation of settlements, the surrounding land supported the majority of its food consumption; this is in contrast to today where the 'rural hinterland' of many cities extends right around the globe. Many medieval European towns were sustainable urban systems, isolated islands of development located within a landscape that supported their resource needs. A besieged city or castle would often have the capability of producing food in order to sustain itself, and in this sense could be perceived as a self-contained, self-sustaining settlement. Ancient Rome, however, could be considered as an example of the contemporary city, in that it drew on increasingly distant resources to feed itself, including Algeria, Morocco and North Africa.

With the majority of the transport of food powered by fossil fuels, the embodied energy of the food is high, and has consequent effects on the greenhouse effect and resource depletion. As an example, the city of Hong Kong produces a significant proportion of its food within the colony's territory, yet still imports 5,985 tonnes of food each day.[3]

Giradet has identified differences between a linear and a circular metabolism for a city. In the case of the former, the city derives its resource needs from a vast area, frequently extending its influence across the globe. However, in the case of a city with a circular metabolism, every output of is utilised as an input into production systems to fulfil its needs, and therefore the area affected by the city is much smaller. In reducing the impact area associated with a city, the production and sources of food become very significant. This principle is also evident in the process of 'environmental footprinting', which is a way in which to represent the resource consumption and waste production of a city. The ecological footprint is expressed as the area of land required in fulfilling and assimilating these demands and pollution. Defined in this way, the ecological footprint of London extends to over 20 million hectares, 125 times

[2] Hough, Michael. *Cities and Natural Process*, London: Routledge, 1995.
[3] Girardet, Herbert. *The Gaia Atlas of Cities - New Directions for Sustainable Urban Living*, Gaia Books Limited, 1992.
[4] Wackernagel, M. and W. Rees. Our Ecological Footprint, British Columbia: New Society Publishers, 1996; and Smith, Maf, John Whitelegg and Nick Williams. *Greening the Built Environment*, London: Earthscan Publications Limited, 1998.

greater than the actual surface area of the city, and almost the equivalent of the entire area of productive land in the United Kingdom.[4]

Research has been conducted in the United States into the methods of bio-intensive farming techniques, which are derived from methods used by the Chinese for centuries. It has been demonstrated that these methods can be used to produce the entire nutritional need of a person on a vegetarian diet, including the compost crops necessary for sustainable production, on an area of land between 185 to 370 m^2.[5] On the basis of the mean level of occupancy of dwellings in the United Kingdom, derived from census data, of 2.4 people per dwelling, this would require a mean land area of 668.9 m^2 per dwelling dedicated to the production of food by bio-intensive techniques. This would be in comparison to a dwelling area, based on the Space Standards: Area benchmark, of 59.8 m^2.

The benchmark of Ecological Significance of the Site will relate to the biodiversity of the site. Therefore, the criterion of green space will be predicated to ensuring that a benchmarked area of productive green space is included with the development of every dwelling, which will contribute to the production of food and the assimilation of CO_2, in addition to providing habitat for wildlife, to the benefit of the biodiversity of the site.

The area of green space provided on a green field site by a national house builder is likely to be higher than that provided in an urban context by the same house builder, to the higher land costs in urban sites. However, for the purposes of consistency in the benchmarking process, the area of green space in proportion to the floor area of the dwelling can be demonstrated through an empirical study. A typical 84 m^2 dwelling was provided with an area of private garden of 165 m^2. This area of green space can be translated into a percentage of the floor area of the dwelling, of 196 percent.

A more urban scenario can be demonstrated by the Laivapoika project in Ruoholahti, a part of the western harbour of Helsinki and a short walk from the city centre, by Helin & Siitonen. Until recent development, the area had been in decay; the city authorities produced a plan for the district, which was intended to give the area the mix of uses synonymous of a proper urban quarter, including a residential element. The site itself is wedge-shaped, with its east apex on a corner of busy roads. A new canal and urban landscaping to the north terminates in a circular basin; this is intended to act as a landmark for the reconstruction of the Ruoholahti district. The complex can be divided into three main pieces: two six stories high, with a north-east corner tower being two stories taller; the tower acts as a prism reflecting light

[5] Weizsacker, Ernst von, Amory B. Lovins and L. Hunter Lovins. Op. Cit.

into the triangular green open space below. Within this space the use of natural materials is detailed with craftsmanship of the industrial style of the surrounding blocks. The overall floor area of the project is 9,947 m^2; the area of green open space has been determined as 2,158 m^2. Therefore the proportion of green open space as a function of the internal floor area can be established as 21 percent.

The benchmark of Green Space for Drawn Study Three is also high, due to the relatively low density and semi-rural location, despite its ambition of an urban village. The benchmark has been established that, accounting for the shared spaces of the allotments and pocket parks and the private gardens of individual dwellings, the proportion of green space as a function of the internal floor area is 237 percent.

Evidently, some of the comparatives made above are not appropriate to informing the benchmark of Green Space for the 'urban house in paradise'. Therefore the decision was made to establish the benchmark on the basis of innovating upon the selected best practice European comparative.

Methodology of Assessment

The criterion will assess the provision of an area of green space in proportion to the scale on the building proposed. The type of space could range from a number of individual private gardens to a semi-private communal area to a public open space. It is a criterion that has been evolved through the research and does not, as far as has been possible to ascertain, have a precedent in other assessments. The evaluation of the benchmark will be made on the basis of the area of productive green space the site, as a function of the total internal floor area of the project.

Although the specific intention is made throughout the thesis to quantify benchmarks in dimensional terms, this is not achievable in terms of the Green Space benchmark, due to the huge, almost infinite, range of potential total floor areas that the 'urban house in paradise' might have. The benchmark is, therefore, quantified as a proportion, and can be converted into a dimensional value, in terms of m^2 or ha, once the area of the dwelling or dwellings is established. This can be summarised in the equation below.

Area of productive green space / total net internal floor area of building(s)

Conclusion

Therefore, the proposed benchmark for the criterion, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative and Drawn Study Four, is proposed in the table below:

	Green Space (%)
Typical UK speculative dwelling	196
European comparative: Laivapoika	21
Drawn Study: 3	237
The 'urban house in paradise'	**25**

Green Space benchmark for the 'urban house in paradise'

3.19 Lifecycle Cost

The cost benchmark is a critically important one. Whilst it could be considered as at odds with improving the performance standards of dwellings; it will provide a 'control monitor' of the comparison between the cost of improving performance standards to create the 'urban house in paradise' as opposed to a standard dwelling, in the context of current innovations in reducing construction costs. The initial view that the cost of a dwelling would be increased through, for example, increasing thermal performance of specifying more efficient heating systems, should be re-evaluated in terms of the lifecycle cost, encompassing both construction and energy costs. Therefore, in the context of holism and the consideration of the lifecycle of a dwelling, created by the matrix of criteria and its attention on sustainability, the cost benchmark will reflect the lifecycle costs of the dwelling in addition to the cost of constructing it.

In the publication *Rethinking Construction* by the Construction Taskforce the proposal is made to reduce the capital cost of construction in the United Kingdom by 10 percent year on year, excluding land and finance.[1] The Movement for Innovation's target reinforces this also. The long-term impact of this continual reduction can be calculated through the following equations:

- to calculate the percentage reduction of the original cost for a given number of years:

  $$y = 100 - (100x \,.\, (0.9^n))$$

  where y = new cost
  x = original cost
  n = number of years

- to calculate the new cost as affected by the percentage reduction for a given number of years:

  $$y = x \,.\, (0.9^n)$$

  where y = new cost
  x = original cost
  n = number of years

The effects of this can be easily demonstrated with a couple of examples. The build cost for a typical dwelling today, with a construction cost of £50,000 would equate to the following:

[1] The Construction Task Force. *Rethinking Construction*, London: HMSO, July 1998.

Original cost	Number of years	Percent reduction	New cost
£50,000	5	59	£29,524.50
£50,000	10	65	£17,433.92
£400.m^{-2}	5	59	£236.20.m^{-2}
£400.m^{-2}	10	65	£139.47.m^{-2}

Effects of the Construction Task Force Report on build costs over time

The Movement for Innovation, the body charged with the task of interpreting recommendations made in the Construction Task Force's report into reality, briefly revised the scope of the reductions in cost. The target was set to achieve:

> ... through sustained improvements and innovation in product design and development, in project implementation, in partnering the supply chain and in production of components:
>
> 10 percent improvements each year in lifetime costs, construction time, productivity and profits.[2]

The change in emphasis to lifecycle is of critical relevance to the matrix of criteria that define the 'urban house in paradise', as one of its primary objectives is to determine the effects on lifecycle costs, both ecological and monetary, of the criteria and their benchmarks. Therefore the matrix should be able to predict, if reasonable assumptions are made, of whether or not 10 percent reductions can be achieved or bettered.

One of the methods that the Movement for Innovation seeks to implement their targets through are Key Performance Indicators (KPIs). Administered by the Construction Best Practice Programme,[3] the ten KPIs are benchmarks that are published annually; they provide a tool for performance measurement of a project or company against the range of standards currently being achieved across the construction industry. The range of project criteria the KPIs assess are: client satisfaction in product, client satisfaction in service, defects, predictability in cost, predictability in service, construction cost, and construction time. The KPIs cover the whole of the construction industry, but have specific benchmarks for these

[2] Movement for Innovation website, 30 June 1999: www.m4i.org.uk
[3] Construction Best Practice Programme's website: www.cbpp.org.uk

criteria for both new build private and new build public housing. In terms of construction cost, the objective of the benchmark is to measure the,

> Change in the normalised construction cost of a project in 1998 compared with 1997, expressed as a percentage of the 1997 cost.[4]

The process requires identifying a comparable project the construction of which commenced one year prior to the one that is to be benchmarked. For both projects the Tender Price Index is determined, and then adjusted to take account of location, function, sizes, and changes in resource cost; this creates the Capital Cost Index for each project. The percentage change between the two Capital Cost Indexes is then determined, and a graph is then used to translate this into a benchmark score.

The value of the KPIs for a specific project can then be compared with the average performance of the rest of the construction industry, either for all construction or for a particular sector. The 1998 average KPIs for the construction cost of new build housing were:

Housing Type	Industry Average Performance
New build housing - Private	- 2 percent
New build housing - Public	- 4 percent

1998 performance of public and private sector housing providers against KPI construction cost

These are, therefore, still a long way from the annual 10 percent reduction advocated by the Construction Taskforce and the Movement for Innovation. It could be possible to use a similar approach to the Movement for Innovation to implement the benchmarks of the 'urban house in paradise'. Rather than proposing that the ideal benchmark is achieved immediately, and incremental increase in the performance could be proposed year on year that would lead toward, within a defined period of for example 10 years, achieving the performance of the 'urban house in paradise'. This would enable housing providers to respond to the new construction methods that might be required, and pacify resistance to their acceptance. This increase would have to be such that it would improve efficiency above the rate of the projected increase in the number of households.

[4] Construction Best Practice Programme. *Key Performance Indicators 1998 - Project Delivery and Company Performance*, London: HMSO, 1999. The normalised cost takes account of factors such as

The Whole Life Cost Forum, a collaborative initiative by all sectors of the construction industry, was established in the spring of 2000.[5] Its aim is to establish a database of whole life cost and performance data, based on the process of benchmarking proposed by the Construction Best Practice Programme. The aim is to provide a way,

> ... of integrating and maximising the effectiveness of capital and revenue spending to achieve best value in decision making.[6]

In lifecycle cost terms, the distinction should be made between the cost effectiveness of improving standards as measured purely against fuel consumption costs, especially in the context of decreasing fuel prices, and the wider impact of costs incurred through environmental destruction and climate change in both financial and ecological terms. The former presents a blinkered outlook that would take no account of the wider cost benefits of introducing increased efficiency, or rather, the costs incurred through not introducing such measures. Lowe and Bell put forward the introduction of carbon pricing on CO_2 emissions, arising from the Kyoto Earth Summit, as an example.[7] They suggest that maintaining the current levels of thermal insulation in the Building Regulations would expose the owners of dwellings to the effects significantly raised fuel prices created by future carbon pricing.

A concept that has been developed that may be appropriate to the construction cost benchmark in an urban sustainability matrix is that of total cost accounting.[8] The principle is that the external costs of environmental degradation arising from the production processes are represented within the internal costing of the product.

Lowe and Bell propose an equation that will provide a simplistic theoretical analysis of the impact of price on energy use. This attempts to provide a methodology for establishing at what point the addition of increasing quantities of insulation cost, in financial terms, more than is saved. Their equation is based on the assumption that the additional cost of insulation does not include additional costs in the structure of the envelope, and that reductions in energy costs is only considered in terms of fuel cost. Their proposal is summarised in the equation overleaf.[9]

---

regional variation in tender costs, from the DETR's Quarterly Building Price and Cost Indices, inflation, and differences in quality, assessed subjectively.

[5] Whole Life Cost Forum website, 29 August 2000: www.wlcf.org.uk.

[6] Ibid.

[7] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.

[8] Curwell, Steve and Ian Cooper. 'The Implications of Urban Sustainability', *Building Research & Information*, Number 26 Issue 1, 1998.

[9] Lowe, Robert and Malcolm Bell. Op. Cit.

$$C = c_i.t + \Delta T.L.\lambda.c_h/t$$

where,
C = lifetime financial cost (£)
c_i = cost of insulation (£.m^{-3})
t = insulation thickness (m)
ΔT = mean temperature difference between inside and outside (K)
L = life span of dwelling (s)
λ = thermal conductivity (W.m^{-1}.K^{-1})
c_h = cost of space heating (£.J^{-1})

The conclusion reached is that optimal thermal insulation of the wall and roof is 220 mm and 310 mm respectively.

The lifecycle cost of the dwelling was evaluated by considering each of the contributing factors to it individually. This analysis is presented in the following text.

Construction Cost

At the time of its submission, the Greenwich Millennium Village project set a benchmark reduction in construction cost of 30 percent. Later, this was translated into a preliminary quantitative benchmark of 995 £.m^{-2} for a 60.9 m^2 mid-floor apartment[10]; this was the typical dwelling type used for all of the Greenwich benchmarks. Subsequent to the change in architects, when HTA Architects left the project and were replaced by Proctor Matthews Architects, further details of the construction and cost of the dwellings were released. Built from timber frame as prefabricated cassettes, the developer pledged that the construction cost would be 653 £.m^2.[11] This cost was an attempt to meet the goals put forward in the *Rethinking Construction.*

The Aire Regeneration Partnership's winning submission for the Allerton Bywater Millennium Community, of which Drawn Studies 3, 4 and 5 are a part, took on board the cost reduction philosophy of the Movement for Innovation. The intention of cutting construction costs was benchmarked by a proposed reduction of up to 19 percent in the first year, and by up to 30 percent at minimum after three years, when comparing like for like in terms of space standards and site conditions. A construction cost benchmark was proposed by one of the national house builders for the build cost of a typical dwelling, of 592 £.m^{-2}. The proposed

[10] English Partnerships. *Greenwich Millennium Village: Draft Benchmarking Manuel: Energy, Water Consumption and Constructional Efficiency Targets (second draft)*, unpublished, 5 May 1999.
[11] Booth, Robert. 'Prescott Sticks to His Guns Over Greenwich Targets', *Building Design*, * April 2000.

construction cost of the dwellings for Allerton Bywater was predicted as 560 £.m^{-2}.[12] However, this new benchmark also included a higher ratio of habitable volume to floor area and a higher standard of specification in thermal performance, and higher performance standards in energy, water and waste consumption. In the Terms of Agreement that followed the submission for the development of the project, English Partnerships included the benchmark of a maximum construction cost of 506 £.m^{-2}; this will be, therefore, the upper limit benchmark for the project. This value can be converted into a lifecycle construction cost that will take into account the design life expectancy of the dwelling of 100 years. Dividing this value by 100 years gives a construction cost per annum over the dwelling's design life of 5.06 £.m^{-2}.

In 1997, a European competition was organised by the French association Peripheriques, intended as the generator for an open forum of ideas.[13] Thirty six architects were invited to design a dwelling based on their own reflections of a new type of single-family house, and the extension of that type into an urban layout; the house was to correspond to a traditional three-roomed dwelling, but that could easily be enlarged to four or five rooms. A stipulation of the competition was that, including plot, architect's fees and taxes, the cost should total no more than FRF 499,900 (£51,732), the costs were validated by GEC Ingéniérie. Internal areas varied greatly, ranging between 58m^2 and 112m^2. This would translate to an equivalent cost of between 739 £.m^{-2} and 461 £.m^{-2}.

The typical construction cost for a dwelling, the baseline benchmark, will vary with different dwelling types. A standard method of cost assessment for the construction cost of new dwellings is provided by the Royal Institution of Chartered Surveyors, in the *Guide to House Rebuilding Costs.*[14] This will provide a complimentary, substantiated source for the cost of the typical dwelling built to current regulatory standards, provided by the housing developer for Allerton Bywater. These values are also divided by 60, the typical design life span of a dwelling, to give a lifecycle equivalent cost. The figures for fees and demolition are removed from the values. These costs are summarised in the table overleaf.

[12] Aire Regeneration Partnership. *contribution to a renaissance 2 - Annexes to the Report*, February 1999.
[13] Peripheriques. *36 Propositions for a Home*, Basel, Switzerland: Birkhauser, 1998.
[14] Royal Institution of Chartered Surveyors. *Guide to House Rebuilding Costs*, London: Connelly-Manton, 1999.

Dwelling Type	Cost (£.m^{-2})	Cost (£.m^{-2})
Detached	528	8.9
Semi-detached	596	10.0
2 storey terraced	584	9.8
3 storey terraced	714	12.0
Bungalow	595	10.0
2 storey block of flats	598	10.1
3 storey block of flats	669	11.3
Mean	**612**	**10.3**

Construction costs for a variety of dwelling types[15]

The potential influence of regional variation should also be accounted for. These are summarised in the table below.

Region	Average Variation Factor
United Kingdom Mean	1.00
East Midlands	0.94
North East	0.94
Yorkshire and Humberside	0.94
Wales	0.94
West Midlands	0.94
Eastern	0.99
South West	0.99
Scotland	0.96
North West	1.01
South East	1.04
Greater London	1.17

Variation in construction cost by region[16]

The construction cost benchmark will embrace the Movement for Innovation benchmark reduction of a 10 percent reduction year on year, and informed by the examples above in

[15] Ibid.
[16] Ibid.

terms of best practice. The value will be divided by the design life span benchmark to give an annual equivalent cost, which will demonstrate the further improvement that can be made on the typical product of a national house builder through increasing the longevity of the dwelling. Therefore an initial benchmark of 592 $£.m^{-2}$ was multiplied by the Movement for Innovation's aspiration of a 10 percent reduction; this value of 532.80 $£.m^{-2}$ is below that of the initial cost estimate for Drawn Study Four, and comparable to the value demanded by English Partnerships. Accounting for the design life span of the dwelling, this equates to an annual equivalent value of 4.44 $£.m^{-2}.a^{-1}$.

Energy Costs

In respect of the Movement for Innovation's focus upon lifecycle, rather than just construction, cost, these scenarios of the costs of a typical dwelling and the Drawn Study 4 three bedroom equivalent dwelling should be translated into construction and lifecycle energy use costs, which will then take account of the higher specification of the Allerton Bywater dwelling. The energy costs will be considered over a 60 year period, as the design life of the typical dwelling. The typical fuel prices are taken from the current Standard Assessment Procedure for the energy rating of dwellings;[17] the fuel consumption of the typical dwelling has been taken from the fuel consumption of a three bedroom dwelling built to current Building Regulations.[18] This, with the respective initial fuel costs, can be summarised in the following table.

Typical Three Bedroom Dwelling:

Function	Consumption (kWh)	Fuel	Cost ($p.kWh^{-1}$)	Cost ($£.a^{-1}$)
Space Heating	7,926	gas	1.295[19]	102.6417
Hot Water	4,548	gas	1.295	58.8966
Pumps and fans	175	elec	5.940[20]	10.395
Cooking	656	gas	1.295	84.59
Lights and App's	3,000	elec	5.940	178.20
Total				**434.72**

Energy consumption and costs for typical dwelling

[17] Building Research Establishment. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, Building Research Establishment, 1998.
[18] BRESCU. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, London: Construction Research Communications Limited, October 1998.
[19] Based on fuel cost in domestic gas bill from Gas Supply Company, 30 April 2000.
[20] Based on fuel cost for domestic tariff in, NORWEB Energi. *A Summary of Electricity Charges*, NORWEB plc, 1 April 2000.

Allerton Bywater Drawn Study 4, 3 bedroom equivalent dwelling:

Function	Consumption (kWh)	Fuel	Cost ($p.kWh^{-1}$)	Cost ($£.a^{-1}$)
Space Heating	1,470	elec	5.940	87.318
Hot Water	included above	-	-	-
Pumps and fans	362	elec	5.940	21.597
Cooking	392	gas	1.295	5.0764
Lights and App's	1,176	elec	5.940	69.8544
Total				**183.79**

Energy consumption and costs for the Drawn Study 4, 3 bedroom equivalent dwelling

Worthy of note is that for one year's consumption, excluding standing charges, the Drawn Study 4, 3 bedroom equivalent dwelling's energy costs are 42 percent that of the typical three bedroom dwelling, or £250.93 less. Clearly this would contribute significantly to the disposable income of the inhabitants.

The comparison of life time energy costs will assume an annual rate of fuel price rise of 2 percent; this figure was used by Lowe and Bell, for their calculation of the cost impact of improving Building Regulation standards, taken the Compliance Cost Assessment prepared for the 1994 Revision to the Building Regulations.[21] Evidently the equation can be kept flexible in order to account for more significant rises in domestic fuel prices, should these become apart, in order that the benchmark can be kept up to date. The effect of this increase on the total energy cost over a sixty year period can be determined in the following equation:

$$y = \sum_{n=59}^{n=0} (x+z).\ 1.02^{n}$$

[21] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.

It could be argued that a 2 percent increase in fuel costs per annum is high in the context of falling fuel prices; however, one must seriously consider if this will perpetuate in the context of the finite life expectancy of fossil fuels. Estimates vary as to the reserves of fossil fuels vary, the British Wind Energy Association states that, "The Government has estimated that remaining reserves in the United Kingdom at current rates of use will last 13 years for oil and 25 years for gas." (British Wind Energy Association. *Wind Energy – The Facts*, London: British Wind Energy Association, 1995.) A shortage

where y = total fuel cost
x = current fuel cost
z = standing charge (if applicable)
n = number of years

Therefore, in summary, the total construction and lifecycle energy costs of the two dwelling types, both based on a 60 year period for purposes of comparability, can be summarised as follows.

Function	Cost (£)	
	Typical dwelling	Drawn Study 4
Space heating	11,706.44	9,958.75
Hot water	6,717.25	included above
Pumps and fans	1,185.57	2463.17
Cooking	9,647.62	578.97
Lights and appliances	20,323.98	7,967.00
Standing charge – gas[22]	2,916.30	2,916.30
Standing charge – electric	3,911.97	3,911.97
Lifecycle total	**56,409.13**	**27,796.16**

Table of lifecycle energy costs for typical and Drawn Study 4 dwelling

On this comparison, the cost per unit and standing charges are assumed to be then same for both dwellings; in reality this may not be the case, as it is the intention to bulk purchase energy at Allerton Bywater, through the Village Company which will be long term stakeholder in the site, which will lead to reduced energy costs. Despite this, on a like for like charge the energy costs for the Allerton Bywater dwelling are £28,612.97, or over 50 percent less, than the equivalent typical three bedroom semi-detached dwelling over a 60 year period. Even if the construction costs of the Drawn Study 4 dwelling were not benchmarked to be comparable, the saving in energy costs would more than finance the additional costs arising from energy saving measures.

of supply, increased difficulty in extracting from more remote sources and increasing demand are all factors that could affect an increase in fuel costs with the next few decades.

[22] The standing charges were taken as 9.39 pence per day for electricity and 7.0 pence per day for gas, from a standard domestic utility bill for a dwelling in Merseyside in August 2000. This was averaged over three years at 364 days per annum and one year at 366 days per annum, to account for leap years.

In terms of lifecycle costs, therefore, the cost of energy over the life span of the dwelling can be determined by the following equation:

$$y = \sum_{n-1}^{0} (x+z) \,.\, 1.02^{n}$$

where y = total energy cost
x = current energy cost
z = standing charge (if applicable)
n = life span (years)

Should more utility companies follow the lead taken by British Gas of abolishing the standing charge on utility bills from January 2000, the lifecycle energy costs will become even more significant. With the standing charge removed, 100 percent of the payment is made on the basis of the quantity of energy that ahs been consumed.

The equation was used to predict the energy cost over the typical three bedroom dwelling and the Drawn Study 4 dwelling over their respective design life spans. These values were then divided by the floor area and the design life span to give energy costs in terms of $£.m^{-2}.a^{-1}$; this will mean that there are comparable units with the construction cost benchmark. The values are 11.15 $£.m^{-2}.a^{-1}$ for the typical dwelling and 7.76 $£.m^{-2}.a^{-1}$ for the Drawn Study 4 dwelling. Because the Drawn Study 4 dwelling has a life span 40 years longer than that of the typical dwelling, the percentage fuel increase has more of an impact, and so the values are closer than one might expect on the annual cost comparison given above.

Water Cost

A similar process can be undertaken to determine the lifetime savings that can be achieved through the use of rainwater and greywater recycling instead of potable mains water. In the United Kingdom the typical consumption for domestic purposes is 160 litres per person per day;[23] the cost of mains domestic water by volume, excluding standing charges, is 70.4 pence per cubic metre,[24] or 0.0704 pence per litre. Therefore, the annual cost of water in the typical dwelling can be determined as £41.11 per person. If the benchmark value of mains potable water for the 'urban house in paradise' were adopted, of 6.5 litres per person per day,[25] this would equate to an annual cost of £1.67 per person. The sewerage charge, which is based on the value of potable consumption, can also be calculated in this manner.

[23] The Water Services Association. *Waterfacts '97*, WSA, 1998.
[24] Value taken from by North West Water domestic utility bill, August 2000.
[25] Refer to Annexe 3.35, Water Consumption: Inhabitation.

At a cost of 50.8 pence per cubic metre, this equates to 0.051 pence per litre; therefore the annual cost for the 'urban house in paradise would be £1.20 per person, as opposed to that of the typical dwelling of £29.67 per person. To determine the lifecycle costs, these values can be put into the equation derived for lifecycle energy consumption:

$$y = \sum_{n-1}^{0} (x + v + z) \, . \, 1.02^{n}$$

where y = total cost
x = current potable water cost
v = current sewerage cost
z = standing charges (if applicable)
n = life span (years)

These two scenarios are put through this equation and the final values divided across the design life span of the dwelling[26] to give values in terms of cost per person per annum of the dwelling's life span. The costs are £174.80 per person per annum for the typical dwelling and £97.85 per person per annum for the 'urban house in paradise'.[27] Despite the very low consumption in the 'urban house in paradise' these two values are very close. This is because of the impact of the cost increase on the annual cost of 2 percent each year across an additional 60 years for the 'urban house in paradise'; the high proportion of standing charges that are the same for both dwellings exacerbates this. If the 'urban house in paradise' were also considered over a 60 year life span, the cost would be £45.71 per person per annum. Although the potable consumption of the 'urban house in paradise' is 4 percent of the typical dwelling, the cost over the same time span is 38 percent; this is due to the high proportion of standing charges.

With the water storage and recycling in the Drawn Study 4 dwelling, the consumption is reduced to 155 litres per person per day; over the 100 year design life span, this equates to an annual equivalent cost of 280.54 $£.p^{-1}.a^{-1}$. This is higher than that of the typical dwelling due to the cost increases over the additional 40 year life span; if, for example the rate of consumption were that of a typical dwelling over 100 years, the cost would be 287.12 $£.p^{-1}.a^{-1}$, £6.58 per person per annum more, or £3290.00 for five inhabitants over the life of the dwelling. If the consumption were that of the Drawn Study 4 dwelling over the 60 year design life span of a typical dwelling, the cost would be 170.79 $£.p^{-1}.a^{-1}$, £4.01 per person per annum less, or £1203.00 for five inhabitants over the 60 year life of the dwelling.

---

[26] 60 years for the typical dwelling and 120 years for the 'urban house in paradise'.

To establish the European comparative for the lifecycle energy and water costs, the comparatives used in the benchmarks of Energy Consumption: Inhabitation and Water Consumption: Inhabitation were used, refer to Annexes 3.16 and 3.37 respectively. The values of consumption were analysed using the methodology established above. The lifecycle energy consumption of the Passive Haus was determined as 7.39 $£.m^{-2}.a^{-1}$. This value is low in comparison to the others due to the very low energy consumption, but also due to the period of life span over which the dwelling was assessed. As the Vale's Southwell dwelling has no mains water supply, the cost of the water, excluding maintenance costs which are discussed below, is zero $£.p^{-1}.a^{-1}$. However, the potential acceptance of the lifestyle adopted by the Vales to achieve this benchmark, for example the use of composting toilets, is potentially problematic, even with these cost savings.

Methodology of Assessment

The lifecycle energy and water costs will be based on the consumption values determined for the respective benchmarks, for the design life span benchmark of 120 years. This value will then be divided across the life span to give a value per annum, in order that it can be comparable with the consumption of dwellings without the same longevity

The energy consumption costs will be based on the consumption in the Energy Consumption: Inhabitation benchmark, and calculated in the same manner as the values for the typical three bedroom semi-detached and the Aire 8100 dwellings above, summarised in the equation below. These can be determined irrespective of any energy generated by the dwelling, in order to provide a value against which to offset the additional cost of energy saving measures, and also the cost of energy generation installations.

The lifecycle costs of water consumption and sewerage charges are also calculated using the formula below, and demonstrated above. The values of consumption are based on the consumption quantities determined in the Water Consumption: Inhabitation benchmark.[28]

---

[27] Refer to attached spreadsheets for the summary of this analysis. Both scenarios are based on the same design occupancy of 5 persons, across which the standing charges are spread.

[28] The values used in the equation are taken as 70.4 pence per cubic metre and 6.55 pence per day standing charge for potable water and 50.8 pence per cubic metre and 3.01 pence per day for sewerage, and 15.93 pence per day for surface water and highway drainage. These values were taken from a standard domestic utility bill for a dwelling in Merseyside in August 2000. Because the consumption is so intrinsically related to the occupancy of the dwelling, the standing charges are divided by 2.4, the mean occupancy level of a dwelling, to give a value in terms of £ per inhabitant per annum.

Energy costs =

$$y = \sum_{n-1}^{0} (x + z) \,.\, 1.02^{n}$$

where y = total energy cost
x = current energy cost
z = standing charge (if applicable)
n = life span (years)

Water costs =

$$y = \sum_{n-1}^{0} (x + v + z) \,.\, 1.02^{n}$$

where y = total cost
x = current potable water cost
v = current sewerage cost
z = standing charges (if applicable)
n = life span (years)

The construction cost as it is a design benchmark, can be determined in design terms from the cost estimates of the quantity surveyor. If the dwelling is being assessed retrospectively, then the actual construction costs can be used. The benchmark should be given in terms of cost per unit floor area as a separate value, and then included within the lifecycle cost in terms of cost per unit floor area per annum, across the design life span, to be consistent with the other values within the lifecycle cost benchmark. This is achieved by dividing the life construction cost by the life span of the dwelling.

It would also be possible to establish the impact of maintenance costs over the life span of the dwelling. The design life span benchmark analysis, refer to Annexe 3.7, can be used to established the replacement of components over the life span of the dwelling, in a similar manner as to which the lifecycle impact of embodied energy is determined, refer to Annexe 3.13. The additional cost of this replacement can then be added to the overall construction cost. However, it has not been possible, within the scope of this research, to establish comparable benchmarks for the maintenance costs of dwellings, and therefore to propose a value for the 'urban house in paradise'.

Conclusion

Therefore, the proposed benchmark for the criterion, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative and Drawn Study Four, is proposed in the table below:

Dwelling	Cost				
	Construction	Energy	Water	Total	
	($£.m^{-2}.a^{-1}$)	($£.m^{-2}.a^{-1}$)	($£.p^{-1}.a^{-1}$)	($£.m^{-2}.a^{-1}$)	($£.p^{-1}.a^{-1}$)
Typical	9.87	11.15	174.80	21.02	174.80
European Comparative	7.68	7.39	0	15.07	0
Drawn Study: 4	5.06	7.76	280.54	12.82	280.54
'urban house in paradise'	4.44	7.96	97.85	12.40	97.85

Lifecycle Cost benchmark of the 'urban house in paradise'

3.20 Nitrogen Oxide Emissions

Oxides of nitrogen, collectively termed NO_X, are produced as a result of the combustion of fossil fuels. In the atmosphere they combine with water to form nitric acids, and are thereby associated with the production of acid rain.

Within the United Kingdom, transport accounts for approximately 56 percent of the emissions of nitrogen oxides, whilst the extraction, distribution and burning of fossil fuels in power stations accounts for a further 28 percent. The domestic sector only produces approximately 3 percent of the national total.[1] The levels of emissions of NO_X in the United Kingdom peaked in 1989, and emissions from road traffic peaked in 1992;[2] in 1994, when the UK produced approximately 2.7 million tonnes of NO_X,[3] they were 9 percent lower than in 1987, and in 1995 fell a further 5 percent.[4] In 1997, the *United Kingdom National Air Quality Strategy* was published. This set the standards and objectives for the reduction of the eight principal health-threatening pollutants, to be achieved by 2005; nitrogen dioxide was included within the Strategy.

The amount of nitrogen released by the burning of fossil fuels depends on the temperature of the burning process and the nitrogen content of the fuel. For example, coal, is comprised of about 1 to 2 percent nitrogen, in crude oil less than 1 percent, and in natural gas between 5 and 10 percent.[5] It is the latter of these fuels that concerns the level of NO_X emissions from dwellings.

Whereas for other fuel sources, where the emissions and efficiency that arise from converting that fuel source into the fuel type used in the dwelling are determined by the power station, such as coal into electricity, for natural gas the emissions and efficiency are determined by the appliances in the dwelling itself. Currently there is no legislation that limits NO_X emissions from small gas boilers, i.e. those below 50MW, although manufacturers are developing and marketing products termed low NO_X.

The specification of a benchmark that is only applicable to gas presents something of a dilemma. Firstly, if an electric heat source were used, then there would be zero NO_X

---

[1] Digest of Environmental Protection and Water Statistics, Number 18, London: HMSO, 1996.
[2] Davison G. and C. N. Hewitt (eds). *Air Pollution in the United Kingdom*, London: The Royal Society of Chemistry, 1997.
[3] BRECSU, 'Low NOx Condensing Boilers in Large Residential Buildings,' Final Report 20, Garston: Building Research Establishment, February 1995.
[4] NSCA. *Pollution Handbook 1998*, London: The National Society for Clean Air and Environmental Protection, 1997.

emissions at the dwelling although, as nitrogen oxides are a by-product of the burning of fossil fuels, they would be produced at the power plant. However, if a Green Tariff were used, which ensures the supply of electricity from a renewable source, then there would be zero NO_X emissions. Therefore, it could be considered that the benchmark for NO_X emissions should be zero, and consequently, eliminating the use of gas as a heat source. However, gas is one of the most efficient fuels types,[6] and has a relatively low CO_2 output in terms of delivered energy against other fuel types;[7] therefore it will be an attractive option to use as a fuel to achieve other benchmarks in the benchmarks of the 'urban house in paradise'. In addition, research demonstrates that the use of gas as a domestic fuel is increasing.[8] Therefore, the matrix of criteria must benchmark the level of efficiency and emissions that arise out of its use, although it should also advocate the use of alternative sources if they collectively reduce the benchmarks, particularly if they are of a higher significance rating in terms of reducing the overall ecological impact of the dwelling.

BRECSU conducted measurements of the NO_X emissions from a large residential building in London, for four months in 1994, following the refurbishment of the heating system during which the existing boilers had been replaced with low NO_X emission condensing gas boilers. With no detrimental effect to the overall efficiency of the system, as compared to a standard condensing boiler, the low NO_X version reduced the annual NO_X emissions by 61 percent. The actual level of emission from the low NO_X condensing boiler was 46 ppm, 95 $mg.m^{-3}$ or 73 $mg.kWh^{-1}$; those from a comparative condensing boiler averaged 118 ppm, 241 $mg.m^{-3}$ or 186 $mg.kWh^{-1}$.

In terms of European comparatives, proposed European limits on NO_X emissions would set a maximum level of 139 ppm. A voluntary standard in Germany, the Blue Angel label, sets a limit of 57 ppm; regulations in Switzerland enforce a maximum of 46 ppm.[9] In terms of emissions relative to energy consumption, these values translate as 246, 101 and 81 $mg.kWh^{-1}$ respectively.

EcoHomes, the most recent issue of the Building Research Establishment's environmental assessment of dwellings included, for the first time, a criterion of nitrogen oxide emissions from gas boilers. The award for compliance is based on three levels of performance: 150, 100 and 70 $mg.kWh^{-1}$, the latter being the highest standard of performance as it has the

---

[5] Bridgman, Howard. *Global Air Pollution*, London: Wiley, 1990.
[6] Building Research Establishment. *Building Performance*, London: HMSO, 1983.
[7] Building Research Establishment, *The Government Standard Assessment Procedure for Energy Rating of Dwellings*, London: HMSO, 1998.
[8] Dunster, J. E., I. Michel and L. D. Shorrock. 'Energy Use in the Housing Stock,' BRE *Information Paper*, IP20/94, Building Research Establishment, December 1994.

lowest level of emission.[10] The benchmark proposed should at least achieve the highest performance of *EcoHomes*; however, whether or not it should be lowered further depends upon the availability of appliances that can exceed the standard of 70 $mg.kWh^{-1}$.

In proposing a new benchmark, therefore, it is crucial to ensure that the proposed value can be achieved through the specification of appliances that are in production, and ideally within the United Kingdom to minimise the embodied energy content. Therefore the manufacturers and distributors of gas boilers were contacted to determine some comparable values of appliances including energy efficient ones, typically condensing gas, that are currently available. Values ranged between 112 and 194 $mg.kWh^{-1}$ for traditional appliances, and 16 to 53 $mg.kWh^{-1}$ for condensing gas boilers.[11] It would therefore be justifiable, if products are available, to set the benchmark below that of the *EcoHomes*.

The value of the Drawn Study comparative was derived from the Glasgow project, as the Allerton Bywater Drawn Studies do not use gas boilers. The benchmark of 70 $mg.kWh^{-1}$ is derived from the condensing gas boiler that it is envisaged would be used within the project.

Method of assessment

The methodology used to assess the level of compliance with this benchmark will be through using manufacturer's data for appliances during their specification. This will be in terms of relative values for emissions per kilowatt, quantified in $mg.kWh^{-1}$. The absolute level of emissions can also be determined once the Energy Consumption: Inhabitation level has been calculated. This will be achieved by multiplying the consumption of the appliance, for example by space and water heating, by the benchmark. For example, for the typical dwelling built to current Regulations, this will be:

$$(7{,}926 + 4{,}548) \times 70\ mg.kWh^{-1} \qquad = 873\ g\ NO_X$$

---

[9] BRECSU. Ibid.

[10] Building Research Establishment. Draft proposals for the revision of the *Environmental Standard*, 1995 edition; and Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.

[11] Personal communication from Caradon Plumbing Solutions, Yorkpark Limited and Atlantic 2000, November 1999.

Conclusion

Therefore, the proposed benchmark for the criterion of Nitrogen Oxide emissions from Gas Boilers, seen in the context of the other comparative benchmarks of the typical speculative dwelling, a European comparative, and Drawn Study Two, is summarised in the table below.

	NO_x Emissions ($mg.kWh^{-1}$)
Typical UK speculative dwelling	153
European comparative: Swiss Regs	81
Drawn Study: 2	70
The 'urban house in paradise'	**60**

Nitrogen Oxide Emission from Gas Boilers benchmark for the 'urban house in paradise

3.21 Other Ecological Impacts of Materials

Whilst other criteria will account for the energy embodied within the materials from which the 'urban house in paradise' is built, and the consequent carbon dioxide emissions from the generation of that energy, there are other forms of environmental degradation caused by the extraction, processing, fabrication and transport of building materials. The criterion of Use of Recycled Materials will have some impact in ensuring that effects of extraction are minimised, by benchmarking a proportion of the materials used to construct the 'urban house in paradise' that are not to be sourced through primary extraction. This criterion and its benchmark aim to ensure that sufficient consideration is given to those effects.

One impact that could be considered is the level of wastage that is associated with the extraction and processing of materials, which can be considered as a form of pollution. This would vary between different materials, but also may be affected by the particular extraction and refinement processes that are used. Some material extraction processes, such as the open cast mining of aggregates, will also have an impact upon wildlife habitat and therefore on biodiversity.

Another impact arising from materials is the pollution caused by fossil fuel consumption during extraction and processing and transportation, above and beyond CO_2 emissions which are accounted under the Ecological Weight: CO_2 Emissions and CO_2 Emissions: Construction Processes criteria. This would include, primarily, sulphur dioxide (SO_2), particulate matter (PM10), nitrogen oxides (NO_X) and carbon monoxide (CO). These values would be different for various materials, not only because of the various levels of embodied energy, but also because of different types of fuels used in the extraction and processing of different materials, as different fuels have substantially different emission factors. This can be seen in the tables overleaf, by comparing the emission per kWh for electricity and gas.

As the fuel ratios for the different quantities of fuels that make up the embodied energy of the materials have not been able to be determined,[1] a value is assumed of 1:1:1 for gas, electricity and petroleum. This will allow a value for the benchmark of emissions to be determined, demonstrating the methodology that is used, for when a true ratio can be determined. This will be measured per kWh of embodied energy; if the ratio is 1:1:1, then

[1] Such values are likely to exist, but this study has not been able to determine them, despite extensive work. It was considered beyond the scope of this research project to calculate these for different material types, but it would be possible to do so in consultation with material manufacturers. The methodology for such a process can be found in Howard, Nigel, Suzy Edwards and Jane Anderson. *BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings*, London: Construction Research Communications Ltd., 1999.

this will be 0.33 kWh of gas electricity and petroleum. Evidently other fuel types can be added if required.

The Building Research Establishment's *Methodology for Environmental Profiles* determines the emissions associated with fuel consumption from the NETCEN National Atmospheric Emissions Inventory, based on 1996 figures which are the most recent available.[2] These figures also take into account the upstream emissions arising from the extraction, refining, and supply, as well as the energy consumed in extraction, refining and supply of the energy to conduct to processes:

Pollutant	Emission factors of fossil fuels (g.kWh^{-1})		
	Gas	Oil	Coal
SO_2	0.008	0.555	2.848
PM10	0.004	0.050	0.315
NOx	0.334	0.480	0.564
CO	0.010	0.051	0.518
VOCs	0.032	0.255	0.065
CH_4	0.403	0.076	0.940
N_2O	0.00036	0.00212	0.02689

Emission factors of different types of fossil fuels

In terms of generating electricity, accounting for the inefficiencies of power stations and transmission after generation means that per kWh of delivered energy the emissions be:

Pollutant	Emission factors of fossil fuels (g.kWh^{-1})		
	Gas	Oil	Coal
SO_2	0.018	1.388	9.493
PM10	0.010	0.125	1.050
NOx	0.835	1.200	1.880
CO	0.025	0.128	1.727
VOCs	0.080	0.638	0.217
CH_4	1.008	0.190	3.133
N_2O	0.00090	0.00530	0.08963

Emission factors for delivered electricity

On the basis of the fossil fuel mix used to generate electricity, derived from the Digest of United Kingdom Energy Statistics 1998[3] (33 percent coal, 31 percent gas, 26 percent nuclear and 2 percent oil), it can be determined that to generate one kWh of electricity will create the following emissions form each fuel type:

Pollutant	Emission factors of fossil fuels (g.kWh^{-1})			
	Gas	Oil	Coal	**Total**
SO_2	0.006	0.028	3.133	**3.167**
PM10	0.003	0.003	0.347	**0.353**
NOx	0.259	0.024	0.620	**0.903**
CO	0.008	0.003	0.570	**0.581**
VOCs	0.025	0.013	0.072	**0.110**
CH_4	0.312	0.004	1.034	**1.350**
N_2O	0.00028	0.00011	0.02958	**0.02997**

Emission factors for delivered electricity per one kWh by fuel type

Therefore, the quantity of emissions that are produced per kWh when derived equally from the three different fuel types can be derived as follows. As described above, should data be determined for the various balances of fuel types for different materials, the ratio of 0.33 can be varied accordingly. Also, other fuel types can be added as necessary.

Electricity:	0.33 x 3.167	= 1.056 $gSO_2.kWh^{-1}$
	0.33 x 0.353	= 0.118 $gPM10.kWh^{-1}$
	0.33 x 0.903	= 0.301 g $NO_X.kWh^{-1}$
	0.33 x 0.581	= 0.194 $gCO.kWh^{-1}$
	0.33 x 0.110	= 0.036 $gVOC.kWh^{-1}$
	0.33 x 1.350	= 0.446 $gCH_4.kWh^{-1}$
	0.33 x 0.02997	= 0.010 $gN_2O.kWh^{-1}$
Gas:	0.33 x 0.008	= 0.003 $gSO_2.kWh^{-1}$
	0.33 x 0.004	= 0.001 $gPM10.kWh^{-1}$
	0.33 x 0.372	= 0.123 g $NO_X.kWh^{-1}$
	0.33 x 0.011	= 0.004 $gCO.kWh^{-1}$
	0.33 x 0.036	= 0.012 $gVOC/.kWh^{-1}$

[2] Howard, Nigel, Suzy Edwards and Jane Anderson. Op. Cit.

	0.33 x 0.448	= 0.148 $gCH_4.kWh^{-1}$
	0.33 x 0.0004	= 0.0001 $gN_2O.kWh^{-1}$
Petroleum	0.33 x 0.642	= 0.214 $gSO_2.kWh^{-1}$
	0.33 x 0.572	= 0.191 $gPM10.kWh^{-1}$
	0.33 x 5.894	= 1.965 g $NO_X.kWh^{-1}$
	0.33 x 3.380	= 1.127 $gCO.kWh^{-1}$
	0.33 x 1.681	= 0.555 $gVOC.kWh^{-1}$
	0.33 x 0.162	= 0.053 $gCH_4.kWh^{-1}$
	0.33 x 0.12378	= 0.041 $gN_2O.kWh^{-1}$

Therefore, in total the pollutant emissions benchmark, on the basis of a 1:1:1 ratio will be:

= 1.27 $gSO_2.kWh^{-1}$
= 0.31 $gPM10.kWh^{-1}$
= 2.389 g $NO_X.kWh^{-1}$
= 1.325 $gCO.kWh^{-1}$
= 0.603 $gVOC.kWh^{-1}$
= 0.647 $gCH_4.kWh^{-1}$
= 0.052 $gN_2O.kWh^{-1}$

Once an accurate ratio of fuel mixes has been determined for a variety of materials, then a more accurate value can be determined; a benchmark reduction could then be proposed on the basis of what is possible through the specification of alternative materials. The purpose that this benchmark will serve is to ensure that in the specification of materials with lower embodied energy, the level of pollution does not in fact increase, due to a change in the ratio for a fuel with much high emissions factors. However, using this value for the present will serve to integrate the benchmark into the matrix of criteria.

The benchmark will also be defined in a further way. *EcoHomes*, the Building Research Establishment's environmental assessment of dwellings also considers the ecological impact of materials. This is based upon the *Green Guide to Housing Specification.*[4] Based on the *Methodology for Environmental Profiles*, it provides a reference guide for the relative environmental impacts of building materials on a scale of A, B or C. The Guide assess the relative impacts of different materials in terms of a number of environmental impacts, including climate change, minerals extraction, toxicity and waste generation.

---

[3] Department of Trade and Industry. *Digest of United Kingdom Energy Statistics 1998*, London: HMSO, 1998.

This is similar to the Environmental Preference Method (EPM), developed in 1991.[5] Its aim is to provide a methodology for the comparative assessment of environmental impact of materials and products used in both construction and refurbishment, during the design process. Over half of the Dutch local authorities use the EPM in drawing up guidelines, and it is used as an evaluation tool in seven EU member states.

The EPM compares materials and products for each element or application in the construction and refurbishment process, and ranks them according to environmental impact; the outcome is not an absolute, valued environmental impact assessment, but rather a scale of preference. Based on the structure of the Life Cycle Assessment (LCA) consideration is given to the whole life cycle of the material or product, from extraction, through production, building, occupation, to decomposition. The principle criteria considered in the assessment are:[6] shortage of raw materials, ecological damage caused by extraction of raw materials, energy consumption at all stages (including transport), water consumption, noise and odour pollution, harmful emissions, global warming and acid rain and waste

The benchmark will include the requirement that all of the material used in the construction of the dwelling achieve an 'A' rating in the *Green Guide to Housing Specification*. This was selected over the Environmental Preference Method as it is predicated exclusively toward housing and has been issued more recently; for both of these reasons it was considered more relevant.

The dwelling in Drawn Studies 4 and 5 will achieve compliance through its use of renewable and recycled materials. It is envisaged that the concrete will contain recycled aggregates, and that at least some of the dwellings will be clad in timber, a renewable resource.

Methodology of Assessment

An evaluation of the pollution emission factors will be based on the mean emissions per kilowatt-hour of embodied energy consumption. This will require that the breakdown of different fuel consumption for the variety of materials that are used in the dwelling is

---

[4] Anderson, Jane and Nigel Howard. The Green Guide to Housing Specification – An Environmental Profiling System for Building Materials and Components, London: Construction Research Communications Limited, 2000.
[5] Anink, David, Chiel Boonstra and John Mak. *Handbook of Sustainable Building - An Environmental Preference Method for Selection of Materials for Use in Construction and Refurbishment*, London: James and James, 1996.
[6] Ibid., p. 8.

ascertained, which will require information that it has not been possible to establish within the scope of the research. Therefore an approximate benchmark, and the methodology for assessing that benchmark in the light of this information, is proposed. The benchmark can be determined by multiplying the proportion of energy consumed by each fuel type of the overall embodied energy by the emission factors for that fuel. The emissions for all of the fuels are then summed. This methodology is demonstrated in the text above.

The benchmark will be in the form of a requirement ensuring that due consideration will have been paid to the level of effects of the materials specified on the given impacts. This will be qualified in the form of a demand that all materials meet classification 'A' of the *Green Guide to Housing Specification.*

Conclusions

The benchmark in terms of the pollution caused through embodied energy will be as follows; this is based on the assumed fuel mix ratio of 1:1:1. As it has not been possible to evaluate comparatives and the Drawn Studies, just the values for the basic benchmark are proposed.

$= 1.27\ gSO_2.kWh^{-1}$

$= 0.31\ gPM10.kWh^{-1}$

$= 2.389\ g\ NO_X.kWh^{-1}$

$= 1.325\ gCO.kWh^{-1}$

$= 0.603\ gVOC.kWh^{-1}$

$= 0.647\ gCH_4.kWh^{-1}$

$= 0.052\ gN_2O.kWh^{-1}$

Total pollution $=$ **$6.596\ g.kWh^{-1}$**

In terms of the wider ecological impacts of materials, the benchmarks are summarised in the table below.

	Other Ecological Impacts of Materials
Typical UK speculative dwelling	C
European comparative:	-
Drawn Study: 5	A
The 'urban house in paradise'	**A**

Other Ecological Impacts of Materials benchmark for the 'urban house in paradise'

3.22 Other Greenhouse Gas Emissions

Whilst in terms of anthropocentric emissions carbon dioxide is the principle gas that contributes to the 'greenhouse' effect of the warming of the planet, others also contribute. The table below summarises these, and their proportion of contribution to warming. The sources of these gases, particularly with reference to the emissions that arise as a consequence of dwellings, are discussed in the text that follows.

Gas	Contribution to Warming (percent)
CO_2	50
Methane	19
Chlorofluorocarbons	17
Tropospheric ozone	8
Nitrous oxide	4

Table of comparative contribution to warming of greenhouse gases[1]

This table is based on the contribution to the greenhouse effect in terms of their relative emission from anthropocentric sources. It should also be borne in mind that these gases have very different potential to contribute to the greenhouse effect in terms of comparable quantity of emissions, for example on the basis of a kiogramme for kilogramme comparison. This can be demonstrated in the table below.

Gas	Warming Potential
CO_2	1
Methane	70
Chlorofluorocarbons	6,000
Tropospheric ozone	2,000
Nitrous oxide	200

Table of potential contribution to warming of greenhouse gases for equal masses[2]

From this table one can deduce that kilogramme for kilogramme, methane has a contribution

[1] Henderson, G. and L. D. Shorrock, 'Greenhouse-gas Emissions and Buildings in the United Kingdom,' *IP2/90*, BRE Information Paper, Garston: Building Research Establishment, April 1990.
[2] Rodhe, Henning. 'A Comparison of the Contribution of Various Gases to the Greenhouse Effect,' *Science*, 8 June 1990.

to the greenhouse effect 70 times that of carbon dioxide, and 200 times for nitrous oxide. Evidently the emission of gases such as tropospheric ozone and chlorofluorocarbons are highly significant.

Methane

19 percent of global warming is caused by methane (CH_4). A reduction in the emissions of some sources of methane will be inherent through other benchmarks within the matrix. The primary source of methane that can be attributed to dwelling is produced in refuse tips by decomposting waste; therefore, the benchmark reduction of domestic waste through recycling will also directly contribute to a reduction in methane production arising from landfill. The burning of fossil fuels to generate energy also causes methane emissions; however, the reduction in energy consumption benchmarked by the criteria of Ecological Weight: Embodied Energy, Energy Consumption: Construction Processes and Energy Consumption: Inhabitation will account for the reduction in these emissions. As the only significant sources of methane production arising from the processes directly associated with the dwelling is benchmarked by other criteria, there is no reason to include them here also.

CFCs and HCFCs

Chlorofluorocarbons (CFCs) follow methane as the next most significant contributor to greenhouse warming. Although only relatively small quantities of the gas are involved, they add to their destruction of stratospheric ozone, an essential barrier which prevents harmful ultraviolet light from the sun reaching the surface of the earth, a level of performance as a greenhouse gas that is ten thousand times that of CO_2.[3] Hydrochloroflourocarbons (HCFCs), which are used as a replacement for CFCs for some foamed plastic thermal insulation materials, have a shorter atmospheric lifetime than CFC, as they contain hydrogen, and are therefore thought to be less damaging to stratospheric ozone; however, they are still considered as greenhouse gases.[4]

Traditionally there have been two uses for CFCs in buildings; firstly as blowing agents in insulation materials, and secondly as refrigerants in air-conditioning. The Montreal Protocol of 1989, on substances that deplete the ozone layer, sought to commit industrialised nations to cut CFC consumption by half by the year 2000. Its subsequent revision in London in 1990 led to the amendment of a complete phase out of CFCs by January 2000.

---

[3] Vale, Brenda and Robert. *Green Architecture - Design for a Sustainable Future*, London: Thames and Hudson, 1991.
[4] Building Research Establisment. 'CFCs in Buildings,' *BRE Digest 358*, Garston: Building Research Establishment, October 1992.

This was followed in 1992 by a revision in Copenhagen to cease the production of CFCs from 1 January 1996.[5] In 1997, the European Union proposed that the timetable leading to a phase out of HCFCs should be tightened, with a new deadline of 2015. This, however, was not included within the 1997 amendment to the Montreal Protocol.[6]

In December 1994, following the reviews of the Montreal Protocol, the European Commission agreed to EC Regulation 3093/94/EC on substances that damage the ozone layer. This bans the use of CFCs from 1 January 1995, and limits the use of HCFCs to, on the base level of 1989, a 35 percent reduction form January 2004, 60 percent from 2007, 80 percent by 2010, 90 percent from 2013 and a total ban from 1 January 2015. However, legislation does concede that in the interim, HCFCs may still continue to be used if there is no alternative substance that can be used in its place. The United Kingdom foam industry is expected to continue using HCFCs until 2004, contributing to the 35 percent reduction required from that date; the total use of HCFCs in the production of foams in 1999 was 523 ODP tonnes.[7]

The reduction of HCFCs will be achieved through the specification of insulation materials that have been produced without using any of the variants of the gas as blowing agents. It has been possible to determine that the manufacturer Cellotex uses the HCFC 141B as a blowing agent in the production of some insulation materials.[8] This has an ozone depletion potential of 0.08 times that of the CFC R11, which is used as the benchmark gas, and has a global warming potential of 150 times that of CO_2.[9]

Despite extensive correspondence being issued to both manufacturers and trade associations, only one manufacturer would supply details of the quantity of HCFC used in the production of insulation foams. In every case where a reason was given for not supplying values, this was due to the confidentiality of such data. Therefore, the calculation of the effect of this benchmark will be based on this value of 140 kgHCFC per tonne of insulation.[10] The only stage at which the gas leaks is during manufacture; when within the dwelling, the gas is held within the insulation, and regulations govern the disposal upon demolition. The

[5] Ibid., Addenda February 1993.
[6] NSCA. *Pollution Handbook 1998*, London: National Society for Clean Air and Environmental Protection, 1997.
[7] March Consulting Group - Department of the Environment, Transport and the Regions. *Proposed New Controls on CFCs, HCFCs, 1,1,1 Trichloroethane and Carbon Tertrachloride – UK Compliance Cost and Impact Study*, London: HMSO, September 1998.
[8] Personal communication with Cellotex and Ecotherm Ltd.
[9] Thomas, Randall (ed). Environmental Design, London: E & F N Spon, 1996.
[10] Two values were given by the manufacturer, one of 140 kgHCFC per tonne for foam with a density of 24 $kg.m^{-3}$ and 95 $kgHCFC.tonne^{-1}$ for foam with a density of 55 $kg.m^{-3}$. The former value is used

value of the proportion of gas released during the manufacture of HCFC insulation is 5 percent.[11]

In terms of insulation materials, alternatives are available that are either non-blown, or are blown with alternative gases that do not have an ozone depletion effect. However one such alternative is CO_2; whilst having no ozone depleting effect, and although the quantities involved are relatively small, CO_2 does also contribute to the greenhouse effect.

The substitution of CO_2 for CFCs can lead to an increase in thermal conductivity, therefore requiring more material to achieve the same level of insulation, and thereby increasing the overall level of embodied energy.[12] However, there are some insulation materials that do not require a blowing agent, for example: cellulose, which is made from recycled news paper, mineral fibre, which can be used for most applications, and cellular glass, which can be used for floor, wall and some flat roof insulation.

The Building Research Establishment's environmental assessment of dwellings, *EcoHomes*, assigns credit for the specification of all insulation materials to have an ozone depleting potential of less than 0.10, and assigns a further credit for the specification of insulation materials that have a zero ozone depletion potential.[13] Bearing in mind the effects of CO_2, the 'house in paradise' would demand that, despite the small quantities involved, CO_2 be not used as a replacement.

In terms of refrigerants, CFCs and HCFCs are found in air conditioning systems as there is the potential to use CFCs recovered from old systems to service existing equipment. In the event that air conditioning is used within the dwelling, sufficient alternatives are available that can work with equal efficiency, so as not to increase energy consumption, to eradicate the use of CFCs and HCFCs.

Therefore, the benchmark proposal for CFCs and HCFCs will be zero, with the requirement that alternatives do not have an ozone depleting or other greenhouse effect potential.

---

because the manufacturer states that this is the one most frequently supplied, as it both reduces material costs and has a better value of thermal conductivity.

[11] Personal communication with Mr G. W. Ball, President of the British Rigid Urethane Foam Manufacturer's Association, 25 April 2000. The communication stated that 5 percent of the added blowing agent is lost during manufacture. None is lost during use, and upon demolition the insulation is collected and combusted to destroy the blowing agent without emission to the air, in accordance with a draft EU Directive on demolition waste.

[12] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.

Tropospheric Ozone

It is increased levels of ozone (O_3) within the troposphere, the atmospheric layer between 6 to 10 km from the earth's surface, which causes a contribution to the greenhouse effect. With approximately an 8 percent contribution to greenhouse warming, tropospheric ozone is formed largely by the action of sunlight on pollution arising, in the case of dwellings, from the burning of fossil fuels.[14] The major source of O_3 is the photolysis of nitrogen dioxide (NO_2), which produces monatomic oxygen (O); this reacts with molecular oxygen (O_2) to form O_3. The contribution of fossil fuel burning contributes to the production of O_3 in two ways. Firstly through the direct emission of N_2O, see below. Secondly, the emission of nitric oxide (NO) from vehicles and other fossil fuel burning accelerates the photolysis process, due to the reaction of NO with water vapour to produce increased levels of NO_2.[15]

The proportion of significant contributors to the emission of nitrogen oxides has varied over time. Evidence suggests that the proportion arising from road transport is increasing in comparison to fossil fuel burning in power stations. In 1986 the percentages were 40 percent for both road transport and power stations;[16] in 1994 49 percent for road transport and 24 percent power stations;[17] and in 1998 47 percent for road transport and 22 percent for power stations.[18] The decrease in emissions from power stations is achieved through the reduction of the number of coal fired power stations, combined with the installation of low NO_X burners to other coal fired stations.

Therefore, like methane, the reduction of tropospheric ozone will be accounted for by the decrease in fossil fuel consumption that occurs as a consequence of the reduction in energy consumption benchmarked by the criteria of Ecological Weight: Embodied Energy, Energy Consumption: Construction Processes and Energy Consumption: Inhabitation. Therefore, rather than creating a specific benchmark for an emission that does arise as a direct consequence of the dwelling, the reduction in emissions is considered to have been accounted for within other criteria.

---

[13] Ibid.
[14] Vale, Brenda and Robert. Op. Cit.
[15] Wellburn, Alan. *Air Pollution and Climate Change*, London: Longman Scientific and Technical, 1994.
[16] Harrison, R. M. (ed). *Pollution: Causes, Effects, and Control*, London: Royal Society of Chemistry, 1990.
[17] *Digest of Environmental Protection and Water Statistics*, Number 18, London: HSMO, 1996.
[18] Department of Trade and Industry. *Digest of United Kingdom Energy Statistics 1998*, London: HMSO, 1998.

Nitrous Oxide

Nitrous oxide (N_2O) contributes approximately 4 percent of greenhouse warming. The production of N_2O that is caused by dwelling also arises from the burning of fossil fuels, both in terms of electricity generation and gas appliances. As with tropospheric ozone, the reduction of N_2O will be accounted for by other benchmarks. The reduction from the burning of fossil fuels will be accounted for by the criteria of Ecological Weight: Embodied Energy, Energy Consumption: Construction Processes and Energy Consumption: Inhabitation; the benchmark of NO_X emissions from gas boilers will include the reduction of N_2O.

Methodology of Assessment

The only probable source of gases that contribute to the greenhouse effect that are not already accounted for, in terms of the benchmarked reduction of their sources, is blown insulation materials using HCFCs. Therefore, in the specification of insulation materials, the designer must ensure, to achieve the benchmark, that no HCFCs are used in its production. The assessment will be based on manufacturer's data; where this is not available the value derived through the research will be used.

The overall emission will be based upon the mass of insulation used. This can be derived from the volume of insulation, which can be calculated from design drawings, which is converted to the mass of the material by its density. The constant that has been derived is 140 gHCFC per kilogramme of insulation; as only 5 percent is emitted during production, the total emissions can be derived by the following equation:

$$\text{emission (gHCFC)} = \text{Mass of insulation} \times 140 \times 0.05$$

Conclusion

Therefore, the comparative benchmarks and the proposed benchmark level of the Other Greenhouse Gas Emissions of the 'urban house in paradise' are summarised in the table overleaf. There are a plethora of comparatives that demonstrate the use of non-HCFC insulation materials, and although one is demonstrated below, it should not be considered that this demonstrates a particular degree of innovation. For the 'urban house in paradise' there will be the additional benchmark requirement that any alternatives should have zero contribution to ozone depletion and the greenhouse effect.

	Other Greenhouse Gas Emissions	
	CFC	HCFC
Typical UK speculative dwelling	0 kgCFC	140 g/kg^{-1} insulation
European comparative: Southwell	0 kgCFC	0 kgHCFC
Drawn Study: 5	0 kgCFC	0 kgHCFC
The 'urban house in paradise'	0 kgCFC	0 kgHCFC

Other Greenhouse Gas Emissions benchmark for the 'urban house in paradise'

3.23 Pollution Emissions: Energy Consumption Inhabitation

As the level of pollution arising from the consumption of fossil fuels varies by fuel type, the level of pollution that the dwelling creates can vary significantly, even if the actual quantity of energy consumed remains the same, by varying the fuel used. The purpose of this benchmark will be to ensure that fuel types are not used that lead to higher levels of pollution, when other alternatives are available.

This criterion will be based upon the level of pollution produced by the energy consumed within the dwelling during inhabitation;[1] the fuel types that are used to fulfil the energy demands of the dwelling will influence this. This criterion will be based on the relative rather than absolute level of pollution, as it is independent of the actual level of energy consumption. If it were based on the absolute level of pollution created by the benchmarked energy consumption, one could comply by cutting the level of energy consumption in half to use a fuel that produces twice the level of pollution per kilowatt-hour. The same effect also applies of the area of the dwelling. Therefore, the benchmark will determined per $kWh.m^{-2}.a^{-1}$, based on the ratio of fuel types used in the dwelling. It will act as a complimentary check to the benchmark of Energy Consumption: Inhabitation.

This assessment can be demonstrated, as well as showing the 'typical' dwelling scenario, by determining the value for a three bedroom dwelling built to 1995 Building Regulation standards.

Function	Energy Use ($kWh.a^{-1}$)	Energy Consumption ($kWh.m^{-2}.a^{-1}$)
Space Heating	7,926 (gas)	94
Hot water	4,548 (gas)	54
Pumps and fans	175	2
Cooking	656 (gas)	8
Lights and Appliances	3,000	36
Total	**16,305**	**194**

Energy consumption of a typical dwelling, built to current standards[2]

[1] The pollution from the embodied energy consumed by the dwelling is accounted for under the benchmark of Other Ecological Impacts of Materials.
[2] BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, London: HMSO, October 1998.

In this case, the total consumption is 194 kWh.m^{-2}.a^{-1}, from 156 kWh.m^{-2}.a^{-1} of gas and 38 kWh.m^{-2}.a^{-1} of electricity; therefore by the ratio of fuel consumption, the consumption per kWh.m^{-2}.a^{-1}, will be 0.76 gas and 0.24 electricity. Under the benchmark of Other Ecological Impacts of Materials, the emissions of pollution per kilowatt-hour were determined for these fuel types.[3] Thus the total emissions per kilo-watt hour can be calculated as follows:

Electricity:	0.20 x 3.167	= 0.633 gSO_2 per kWh.m-2.a^{-1}
	0.20 x 0.353	= 0.071 gPM10 per kWh.m-2.a^{-1}
	0.20 x 0.903	= 0.181 gNO_X per kWh.m-2.a^{-1}
	0.20 x 0.581	= 0.116 gCO per kWh.m-2.a^{-1}
	0.20 x 0.110	= 0.022 gVOC per kWh.m-2.a^{-1}
	0.20 x 1.350	= 0.270 gCH_4 per kWh.m-2.a^{-1}
	0.20 x 0.02997	= 0.006 gN_2O per kWh.m-2.a^{-1}
Gas:	0.80 x 0.008	= 0.006 gSO_2 per kWh.m-2.a^{-1}
	0.80 x 0.004	= 0.003 gPM10 per kWh.m-2.a^{-1}
	0.80 x 0.372	= 0.298 gNO_X per kWh.m-2.a^{-1}
	0.80 x 0.011	= 0.009 gCO per kWh.m-2.a^{-1}
	0.80 x 0.036	= 0.029 gVOC per kWh.m-2.a^{-1}
	0.80 x 0.448	= 0.358 gCH_4 per kWh.m-2.a^{-1}
	0.80 x 0.0004	= 0.0003 gN_2O per kWh.m-2.a^{-1}

= 0.639 gSO_2 per kWh.m^{-2}.a^{-1}
= 0.074 gPM10 per kWh.m^{-2}.a^{-1}
= 0.479 gNO_X per kWh.m^{-2}.a^{-1}
= 0.125 gCO per kWh.m^{-2}.a^{-1}
= 0.051 gVOC per kWh.m^{-2}.a^{-1}
= 0.628 gCH_4 per kWh.m^{-2}.a^{-1}
= 0.006 gN_2O per kWh.m^{-2}.a^{-1}

= 2.002 g pollution per kWh.m^{-2}.a^{-1}

Comparing the above values for the emissions from gas and electricity demonstrates the point that different fuel types create different levels of pollution. These are summarised in the table below:[4]

[3] Please refer to Annexe 6.22.
[4] These values are based on values taken from NETCEN National Atmospheric Emissions Inventory, and are adjusted to take account of upstream combustion factors, and the ratios of primary to

Fuel	Pollutant (g.kWh^{-1} delivered)							
	SO_2	PM10	NO_X	CO	VOC	CH_4	N_2O	Total
Coal	2.885	0.319	0.598	0.525	0.066	0.952	0.027	5.372
Electricity	3.167	0.353	0.903	0.581	0.110	1.350	0.030	6.494
Fuel oil	4.200	0.103	0.767	0.073	0.285	0.092	0.002	5.522
Gas	0.008	0.004	0.372	0.011	0.036	0.448	0.0004	0.879

Pollutant emissions in terms of delivered energy for different fuel types

Of course, if the electricity that is consumed by the dwelling is generated from natural, non-polluting, renewable sources, such as wind and solar power, then the pollution will be zero. This can be a value determined in terms of net consumption, for though pollution will be created whilst mains electricity is consumed, when an excess of energy is being put back into the grid, pollution creation elsewhere will be abated. Therefore, the net pollution will be zero.

This issue becomes increasingly important as the energy consumption of the dwelling is reduced, because when the space and water heating component is cut significantly, the relative proportion of consumption by other sources increases. These other sources are frequently ones that consume electricity, such as lighting and appliances. For example, it can be seen that for the 'typical dwelling' the consumption of gas and electricity might be 156 kWh.m^{-2}.a^{-1} and 38 kWh.m^{-2}.a^{-1} respectively, a ratio of 0.8:0.2. From the benchmark analysis for the Energy Consumption: Inhabitation criterion,[5] it can be seen that the energy consumption of the 'urban house in paradise might be 15 kWh.m^{-2}.a^{-1} gas and 10 kWh.m^{-2}.a^{-1} electricity, a ratio of 0.6:0.4. Therefore, the emission of pollution per kilowatt-hour would be higher in the 'urban house in paradise', due to the higher value of electricity consumption in the ratio of fuel types.[6]

The benchmark of this criterion for the 'urban house in paradise' is to be informed by the benchmarks of Energy Consumption: Inhabitation and Energy Generation: Inhabitation. The benchmark will not be set so high as to demand that 100 percent of the energy of the

delivered energy efficiency. In: Howard, Nigel, Suzy Edwards and Jane Anderson. *BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings*, London: Construction Research Communications Limited, 1999.

[5] Please refer to Annexe 6.15.

[6] This is if all of the electricity consumed by the 'urban house in paradise' is taken from the grid supply.

dwelling is generated from non-polluting renewable sources, which would be 0.000 g pollution.$kWh^{-1}.a^{-1}$, to allow a degree of variability in the specification of fuel sources. The benchmark for energy generation will be sufficient to encourage renewable sources. The value will be based on the assumption that a proportion, 50 percent, of the energy will be derived from renewable sources. The remainder will be derived from a pollution value on a mixture of sources to allow a degree of choice in determining which fuels a dwelling should be powered by. This mixture will based on a value of 40 percent gas and 10 percent electricity, as it is the electricity demands that renewable sources are most likely to replace.

As the Passive Haus in Darmstadt was used as the European comparative dwelling in the Energy Consumption: Inhabitation benchmark, it will be used here also, as the pollution emissions benchmark is a complimentary check to the benchmark of Energy Consumption: Inhabitation. The overall energy consumption was 32 $kWh.m^{-2}.a^{-1}$, from 15 $kWh.m^{-2}.a^{-1}$ of gas and 17 $kWh.m^{-2}.a^{-1}$ of electricity. Therefore the proportion of each fuel type of the energy consumption per kWh can be established as 0.47 gas and 0.53 electricity. The table of emissions above can be used to determine the total pollution emissions from this consumption. This is summarised below.

Electricity:	0.53 x 3.167	= 1.679 gSO_2 per $kWh.m^{-2}.a^{-1}$
	0.53 x 0.353	= 0.187 gPM10 per $kWh.m^{-2}.a^{-1}$
	0.53 x 0.903	= 0.479 gNO_X per $kWh.m^{-2}.a^{-1}$
	0.53 x 0.581	= 0.308 gCO per $kWh.m^{-2}.a^{-1}$
	0.53 x 0.110	= 0.058 gVOC per $kWh.m^{-2}.a^{-1}$
	0.53 x 1.350	= 0.716 gCH_4 per $kWh.m^{-2}.a^{-1}$
	0.53 x 0.02997	= 0.0016 gN_2O per $kWh.m^{-2}.a^{-1}$
Gas:	0.47 x 0.008	= 0.004 gSO_2 per $kWh.m^{-2}.a^{-1}$
	0.47 x 0.004	= 0.002 gPM10 per $kWh.m^{-2}.a^{-1}$
	0.47 x 0.372	= 0.175 gNO_X per $kWh.m^{-2}.a^{-1}$
	0.47 x 0.011	= 0.005 gCO per $kWh.m^{-2}.a^{-1}$
	0.47 x 0.036	= 0.017 gVOC per $kWh.m^{-2}.a^{-1}$
	0.47 x 0.448	= 0.211 gCH_4 per $kWh.m^{-2}.a^{-1}$
	0.47 x 0.0004	= 0.0002 gN_2O per $kWh.m^{-2}.a^{-1}$

= 1.683 gSO_2 per $kWh.m^{-2}.a^{-1}$

= 0.189 gPM10 per $kWh.m^{-2}.a^{-1}$

= 0.654 gNO_X per $kWh.m^{-2}.a^{-1}$

= 0.313 gCO per $kWh.m^{-2}.a^{-1}$

$= 0.075$ gVOC per $kWh.m^{-2}.a^{-1}$

$= 0.927$ gCH_4 per $kWh.m^{-2}.a^{-1}$

$= 0.002$ gN_2O per $kWh.m^{-2}.a^{-1}$

$= 3.843$ g pollution per $kWh.m^{-2}.a^{-1}$

The same process was also carried out for Drawn Study 5, on the basis of 35 $kWh.m^{-2}.a^{-1}$ electricity consumption, as all sources of consumption are assumed to be electricity. The benchmark was determined as 6.494 g pollution per $kWh.m^{-2}.a^{-1}$. That two dwellings with very low energy consumption were above that of the 'typical' baseline benchmark above emphasises the challenge in achieving the benchmark.

Methodology of Assessment

The assessment will be based on the values of design energy consumption as predicted by the Energy Consumption: Inhabitation benchmark. This will be broken down into a ratio by fuel type, in terms of the ration per kilowatt-hour of the total energy consumption. The standard values in that table above can then be used to determine the level of emissions; an account will have to be made of the efficiency of the fuel consumption, as these values are based on the emissions per kilowatt-hour of energy as delivered. This will then account for the relative efficiencies of the appliances specified within the dwelling. A gross value will be determined on the basis of assuming that electricity consumption is provided by mains sources. This will provide a scenario for when no renewable energy is being generated

A net benchmark, in terms of the balance between energy consumption and generation, can then be determined, by deducting the value of pollution emissions that are saved by the use of renewable energy from the gross benchmark.

Conclusion

The benchmark of pollution arising per kilowatt-hour from the energy consumed during the period of inhabitation of the 'urban house in paradise' is given below, and shown in comparison with the 'typical' dwelling, a drawn study and a European comparative in the table overleaf.

	Pollutant (g.kWh^{-1} delivered)							
	SO_2	PM10	NO_X	CO	VOC	CH_4	N_2O	**Total**
'Typical'	0.639	0.074	0.479	0.125	0.051	0.628	0.006	**2.002**
Passiv Haus	1.683	0.189	0.654	0.313	0.075	0.927	0.002	**3.843**
D S 5	3.167	0.353	0.903	0.581	0.110	1.350	0.030	**6.494**
'u h in p'	0.320	0.038	0.240	0.063	0.026	0.314	0.003	**1.004**

Pollutant emissions: Energy Consumption Inhabitation benchmark for the 'urban house in paradise'

3.24 Procurement Strategy

Procurement can be defined as:

> "... a strategy to satisfy the client's development and/or operational needs with respect to the provision of constructed facilities for a discrete life-cycle."[1]

The best strategy or process by which a client can obtain the dwelling in its built form will define the procurement benchmark for the 'urban house in paradise'. Providing benchmarks of the design is not always sufficient to ensure the realisation of these standards in the constructed dwelling. For example, the air tightness target is achieved through both design detailing and high quality of construction, requiring communication between the designer and contractor of the principles involved and their significance in the overall performance of the dwelling. What this shows is that creating the desired performance standards in the constructed dwelling will require the right communication between the designer and the contractor, of the technical principles involved, and of the construction implications of the benchmarks. This is a two way communication that will be best commenced as early as possible in the process, so that construction issues can be fed back into the design process.

Significant drives have been put forward in the recent past to improve the relationship and communication between the parties involved in the design and realisation of construction projects. This could be said to have been initiated by the Latham Report in 1994,[2] and subsequently with the work of the Reading Construction Forum, published in the *Seven Pillars of Partnering* in April 1998,[3] and the Construction Task Force report, *Rethinking Construction* published in July 1998,[4] and subsequently by the work of Movement for Innovation and Construction Best Practice Programme.

The so-called 'traditional' procurement route, typically used by the national house builders to procure subcontractors, is competitive fixed price tendering and lump sum contract. This suffers the disadvantage of separating the fields of the design and construction, with a potentially adversarial connection between the parties involved, and thereby reduces the potential for the transfer of knowledge between the relevant parties, as well as any transparency. Probably the only advantage of this route, in terms of the benchmarks proposed, is that there is an in-built incentive for the contractor to manage the work

---

[1] Professor Colin H. Davidson (ed.), *Procurement - The Way Forward*, IF Research Corporation, 1998, p. 79.
[2] Latham, Michael. Constructing the Team: *Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry: Final Report*, London: HMSO, 1994.
[3] The Reading Construction Forum. *The Seven Pillars of Partnering*, London: HMSO, April 1998.
[4] The Construction Task Force. *Rethinking Construction*, London: HMSO, July 1998.

effectively and to complete the work as quickly as possible, so as to maximise profit. However, this could be at the detriment of other benchmarks, such as air tightness and thermal performance, where emphasising the rate of construction may lead to poorer standards of construction.

Furthermore, in traditional procurement the potential benefits gained through time and production cost savings, inherent to the Construction Task Forces' aspirations, are lost to the client and only the contractor gains. This may be particularly relevant on repetitive jobs, through a learning curve reducing time further, and is therefore more pertinent to the Construction Task Force who seek to reap the benefits given by long term relationships between clients, project teams and suppliers, and share these benefits within the team.

In *Rethinking Construction* principles are put forward for alternative procurement strategies as opposed to competitive tendering, to produce best value and innovation in the construction industry, and with specific reference to housing.[5] The principal criticisms of competitive tendering by the Construction Task Force are of its focus towards lowest initial price, and its lack of ability to differentiate between lowest price and *best value*; also, they perceive competitive tendering as conducive to the fragmentation and adversarial nature of the United Kingdom construction industry.

The Millennium Community competitions are one vehicle that intended to foster more integrated team approaches, so-called 'joined-up thinking,' to innovative high quality design and construction in housing and mixed function projects, and intended to create increased transparency between the parties throughout the evolution of the project. This was procured through consortium submissions to design-led competitions; it was a specific demand that consortia submitting for the Allerton Bywater Millennium Community competition include a national house builder from the outset, in an attempt to evolve a team approach.

Included within *Rethinking Construction* is the proposed introduction of performance measurement against clear targets for improvement, in particular in terms of quality, time and cost. It is benchmarking that provides the route to measuring projects against these, and other, targets. The Stage Two Development Brief for the Allerton Bywater competition used benchmarks in defining performance standards of the dwellings that were to be proposed by the consortia. These included 50 percent reduction in energy consumption, 50 percent reduction in household waste, 30 percent reduction in construction cost, 25 percent

[5] Ibid.

reduction in construction time, and zero defects at handover.[6] The key benchmarks that were then proposed by the winning consortium, the Aire Regeneration Partnership, over and above those demanded by English partnerships, such as the construction cost benchmark, were built in the Heads of Terms Agreement, to ensure their delivery.

The Greenwich Millennium Village, the first of the Millennium Community competitions won in February 1998 by a consortium led by developers Countryside Properties and Taylor Woodrow with the Swedish based architect Ralph Erskine accompanied by the British practice HTA Architects, was also intended as a model of the procurement of innovative new urban housing design and construction. During its initial development the Greenwich team displayed the signs of an integrated approach, including members of the contractor's team based in the offices of HTA Architects.[7] The procurement route envisaged was an early phase of Construction Management; when 80 per cent of the value is let, it would be translated to a Design and Build contract. More design was to be done by specialist suppliers, therefore subcontractor packages in the Construction Management period are Design and Build subpackages, therefore have to be open in terms of basic design.[8] However, eighteen months after the announcement of the winning consortium it had ceased to be a model of the integrated team working in a non-adversarial climate, as espoused by Latham and the Construction Task Force, with the termination of HTA's appointment by the development team, and the intentions of HTA to take out, "... a very substantial legal action ..." against the consortium.[9]

The disintegration of the consortium at Greenwich was, according to HTA Architects, due to the fatal compromising of the innovation of the original design which led to a project that bore no resemblance to the original. This, they claim, arose as a result of lack of co-ordination between the consortium's members.[10] A report by the Tavistock Institute four months before has said of the project,

> Such a lack of understanding and implementation of management process, if allowed to continue, would be a prime indicator of impending disaster. Something needs to be done.[11]

---

[6] English Partnerships. *Millennium Communities Competition - Allerton Bywater Stage Two Development Brief*, 1998.
[7] From interview with Richard Hodgkinson of Taylor Woodrow, at the offices of HTA Architects on 12 October 1998.
[8] Op. Cit.
[9] Slavid, Ruth. 'Developer Sacks HTA in Millennium Village Chaos,' *The Architects Journal*, 1 July 1999.
[10] Architects in Housing Website, 11 July 1999: www.aih.org.uk
[11] Slavid, Ruth. 'RIBA: Erskine Should Resign Too,' *The Architects Journal*, 8 July 1999.

This serves to emphasise the importance of not just creating a consortium, but creating the right structure and communication within that consortium.

The lack of understanding by some members of the team has also caused problems in the procurement of Allerton Bywater. The design team was under constant pressure from the house builders to revise the masterplan in a manner that would be detrimental to some of its fundamental principles, to the extent that the design team repeatedly felt forced to consider their future in the project. Whilst negative opinion can be as much assistance to the evolution of a project as positive, it is considered that the house builders have provided only one beneficial contribution to the project's evolution, which was to encourage a further diversity of dwelling types, from twelve to thirty. The reason for this was based purely on the desire to widen the potential market targets, so as to increase the potential sales.

An advantage of the development brief based consortium competition is that they can be used to also procure excellence in design quality, as well as performance standards. However, as noted in the Urban Task Force report, whilst competitions are becoming increasingly used for high profile projects, there is still some way to go to transform the culture of the development industry, particularly the volume housing sector.[12] The Task Force also observed the way that in other European countries competitions are used as a mechanism to test innovative urban design approaches.

They will, of course, be a cost and time implication in the use of competition. The Urban Task Force emphasises the need to allow sufficient time for the development of an appropriate and rigorous brief that communicates explicitly the aims and objectives, and for competitors to develop solutions; this could vary from three to twelve months. The importance of composing an appropriate caliber of assessment panel to both draw a high level of entry from participants, and to guarantee the selection of a high quality solution, is also emphasised. An approximate value for the cost of the competition process is proposed as up to half a percent of the total build costs. This could add to both the time and cost benchmarks of the 'urban house in paradise'.

A potential disadvantage of the consortium approach is that, whilst it may contribute to a higher quality of design and innovation, it may also lead to a loss of cost control compared to other procurement routes. Because the team is constructed at a very early stage, to ensure that all parties can participate in the development of the design, the opportunity for cost-

---

[12] Urban Task Force. *Towards an Urban Renaissance - Final Report of the Urban Task Force*, London: E & F N Spon, 1999.
[13] Professor Colin H. Davidson (ed). Op. Cit., p. 17.

based competition is lost. This aspect was overcome at the Allerton Bywater project by the inclusion of a maximum build cost benchmark in the Terms of Agreement, refer to Lifecycle Cost, Annexe 3.19.

In March 2000, approximately one year after the competition was one, English Partnerships felt forced to wrest control of the Allerton Bywater project back from the house builders and to assume control of the project. This resulted in a significant reduction in the role of the house builders in the project. Rather than being responsible for delivering the whole project, the house builders would only deliver the housing component, with the mixed-use elements, a central part of the project, being procured independently through English Partnerships. This was a major turn around from the original brief. Aire Design, the architects of the competition entry, were then employed directly by English Partnerships to oversee the delivery of the masterplan and its original aspirations, and by the house builders over the delivery, in part, of the housing. Executive architects were employed to assist in delivering the housing.

The essence of procurement is essentially the apportioning of risk. Since Corbusier drew the comparison between the automotive industry and architecture, notably in *Vers une Architecture* first published in 1923, the similarity and difference of these two fields has frequently been cited. Perhaps in terms of the 'urban house in paradise' the comparison should be made with a Formula One racing team. Formula One demands a holistic team contribution at the highest standard of performance and innovation. Perhaps the important point to draw is that each member of the Formula One team is working toward a shared goal, and not the maximum profit for their particular section of the team, with the whole team accepting the responsibility of risk equally.

To innovate successfully, it is often necessary to adjust the context of a procurement strategy. Ezra D. Ehrenkrantz, of the New Jersey Institute of Technology in Newark, America, in a paper entitled *Procurement and Innovation - Some Successful Strategies*[13] identified that the procurement of innovation was related to both the scale of the market and the time available for innovation. If a procurement strategy is structured so that a significant amount of time is available at the early stages of the project, a large amount of research and development can take place; however, the market itself will have to be of sufficient scale to facilitate amortising that research and development. It is clear that innovation requires an increased design period. Therefore the procurement strategy must be one that facilitates this. Also, members of the design and construction team working together from the earliest possible stages can best achieve innovation; an example of this is the need to improve the air-tightness of the dwelling, which can have significant benefits in reducing the energy consumed in the dwelling during inhabitation. As described above, the achievement of a reduction in infiltration requires both a high standard of detailing by the designer and a high standard of construction quality to execute that detailing, that would have to come from an understanding of the principles and need for air-tightness. By working with a contractor at an early stage, the importance of quality in achieving such a benchmark can be communicated, but more importantly, the contractor can either assist in providing input into the construction techniques that may best achieve the target, or become aware that they may not be able to work within such demands, and fall out to be replaced at an early stage. *Rethinking Construction* acknowledges that innovation requires an increased design period. Therefore the procurement strategy must be one that facilitates this.

There will be benefit in creating a mechanism that retains an 'interest' of the members of the design and construction team in the post-completion performance of the dwelling. This is when it will be determined whether or not a significant proportion of the benchmarks, such as air-tightness and energy consumption during inhabitation, have been achieved. Ideally this will in a manner that does not engender an adversarial climate between those parties, and does not, therefore, add significant cost increases due to a perceived increase in risk liability. In theory, if members of the team are brought together earlier, they have an increased opportunity to achieve the specified demands, and therefore reduce risk. Ideally the opposite would be the case, where all members in the procurement process would share in the profit of the project, and therefore create an incentive to innovate successfully.

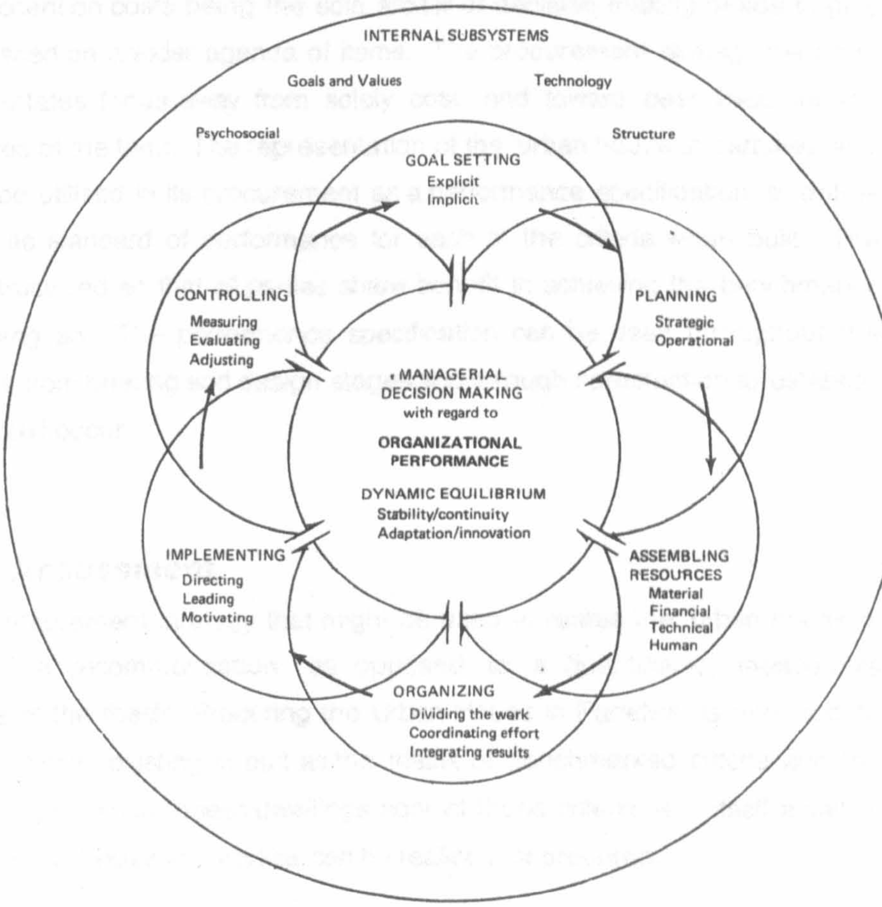
The avocation of the increased development of a team approach to a project, or a series of projects, through a process that utilises the full construction team in *Rethinking Construction*[14] has a precedent in the contemporary management philosophy of Total Quality Management (TQM):

> ... which seeks to control value creation through clear working relationships between the various specialists within the value system.[15]

In terms of a link between TQM and procurement, Kast and Rosenzweig's definition of internal field presents a model that, as a way of improving communication and transparency, might epitomise the relationships envisaged by the Construction Task Force. This is demonstrated in the diagram overleaf.

---

[14] The Construction Task Force. Op. Cit., p. 21.
[15] Gerry Johnson and Kevan Scholes. *Exploring Corporate Strategy*, London: Prentice Hall, 1993, p. 134.



Internal Subsystems as a model for communication within a team[16]

Another point that can be gleaned from the experiences of the Millennium Community Competitions is that one of the potential procurement routes through which to influence innovation in construction would be through the use of performance specifications. These can be used to specify the performance required within a project.[17] The increasing scope of benchmark performance indicators could be expanded and be built into the procurement strategy. Recognising that the construction process begins at the briefing stage, innovation can be initiated by, or defined with, the client, defining the performance that is required. Benchmarking performance could also be part of a regulatory drive, as a consequence of Government initiatives to achieve its reduction targets for carbon dioxide emissions, placing more stringent demands on energy consumption by new and refurbished dwellings, therefore placing an onus upon the whole team.

In order to address the need for change promoted by the benchmarked criteria of the 'urban

[16] Kast, F. and J. Rosenzweig. *Organisation & Management*, London: McGraw-Hill, 1985, p. 402.

house in paradise', accent on costs being the sole arbiter of decision making needs to give way to value being placed on a wider agenda of items. The procurement strategy needs to be adopted that orientates focus away from solely cost, and toward *best value* for the consumer, in all senses of the term. The representation of the 'urban house in paradise' as a matrix of criteria can be utilised in its procurement as a performance specification, to define what is expected of its standard of performance for each of the criteria when built. The contract should be structured so that all parties share benefit in achieving the benchmarks, and liability in not doing so. The performance specification can be used throughout the procurement process, from briefing and design stages and through construction to establish where innovation should occur

Methodology of Assessment

The criterion of the procurement strategy that might be used to realise the 'urban house in paradise' is more of a recommendation, as opposed to a quantifiable, measurable benchmark. The title of the thesis 'Procuring the Urban House in Paradise' is intended to demonstrate that the thesis, existing in part as the matrix of benchmarked criteria and the methodology for a design team to assess dwellings against those criteria, is in itself a part of the way in which the 'urban house in paradise' can be realised, or procured.

Therefore compliance, if that is considered appropriate, can be established as to whether or not the proposed system, of performance specification through the matrix of benchmarks, is adopted or not.

Conclusions

Therefore, the comparative benchmarks and the proposed benchmark level of the life span of the 'urban house in paradise' are as summarised below:

	Procurement Strategy
Typical UK speculative dwelling	Competitive tender; lump sum contract
European comparative:	Not applicable
Drawn Study: 3, 4 and 5	Design competition, one-off contract
The 'urban house in paradise'	**Performance specification**

Procurement benchmark for the 'urban house in paradise'

[17] The Aqua Group. *Tenders and Contracts for Building*, London: BSP Professional Books, 1990.

3.25 Quality of the Internal Environment: Indoor Pollution

The 'urban house in paradise' has been benchmarked to be considerably more airtight than typical dwellings currently are in the United Kingdom. In dwellings with a very low air leakage and strict ventilation rates the problems of indoor air pollution may be exacerbated. Therefore, there is justifiable cause to propose more demanding standards than might otherwise be considered sufficient in terms of high performance dwellings. Indoor pollution is most frequently caused by emissions from materials used within the dwelling and polluted air entering from outside.

For example, the Canadian Residential Energy Efficiency Database (CREED) also makes recommendations on the air quality of the internal environment. The range and proposed acceptable levels of the pollutants within the Database are summarised below:[1]

- Nitrogen dioxide (NO_2). The acceptable short-range exposure range (ASTER) for residential indoor air is <0.25 parts per million (ppm), or <480 microgrammes per cubic metre, for one hour average exposure.
- Carbon monoxide (CO). The average indoor levels of CO vary from 0.5 to 5 ppm. The ASTER, as recommended by Health Canada, for CO in indoor residential air is <11 ppm for eight hour average concentration, or <25 ppm one hour average concentration.
- Formaldehydes. Health Canada proposes two levels of formaldehyde exposure: Action and Target, Action is the level to be achieved immediately and Target as a long-term objective. The values are Action - 0.10 ppm or 120 microgrammes per cubic metre; Target - 0.05 ppm or 60 microgrammes per cubic metre. The Database specifically states that urea formaldehyde foam insulation is not to be used.
- Ozone. The acceptable ASTER as recommended by Health Canada in residential air is <0.12 ppm, or <240 microgrammes per m^3, both one-hour average concentrations.
- Radon. The principal source of radon is the soil surrounding the earth's crust. Therefore air tightness of the basement and foundation construction is an important consideration in excluding it. Some materials, such as phosphate slag in concrete and gypsum board are potential sources; the use of mechanical ventilation and heat recovery (MHVR) is recommended to extract it. In terms of level, Health Canada recommends that levels are as low as possible, as radon is a potential human

[1] Residential Energy Efficiency Database website, 21 July 1999: www.its-canada.com/reed/iaq/no.htm

carcinogen. Remedial action is taken when the average annual concentration in normal living areas is greater than 800 Becquerels (Bq) per cubic metre.

- Volatile organic compounds (VOCs). Over 400 VOCs have been identified in dwellings, over 200 of which can be found in carpets. The principal sources are synthetic and composite materials used in construction, finishing and furnishing the dwelling. The use of these materials should be limited, and the inclusion of MVHR with 0.3 $ac.h^{-1}$ to extract the pollutants is recommended.
- Carbon Dioxide (CO_2). The acceptable long-term exposure range (ALTER), as recommended by Health Canada of in indoor air is <3,500 ppm or < 6,300 milligrammes per cubic metre. The use of balanced MHVR for extraction of the pollutant is also recommended.

For the 'urban house in paradise' the problem associated with these benchmark levels is that the majority have to be assessed post completion, and are therefore not suited to inclusion in a matrix of design criteria, due to the difficulties in validating that the performance meets the benchmark at the design stage. However the inclusion of balanced MVHR with a sufficient rate of air change of at least 0.3 $ac.h^{-1}$, as advocated by CREED, would at least ensure that the build up of these pollutants is prevented. This should be achieved in the 'urban house in paradise', through the Indoor Quality of the Internal Environmental: Ventilation benchmark of 0.45 0.3 $ac.h^{-1}$, refer to Annexe 3.27.

The Building Research Establishment's *Environmental Standard* included a mandatory credit for 'hazardous materials', for which it covers four materials: formaldehyde emissions, wood preservatives, asbestos and paints with added lead, for the purpose of eliminating,

> ... minor or occasional health risks which are not at present covered by regulations and to reduce the unnecessary use of wood preservatives ...[2]

Formaldehyde is emitted from many building materials, including particleboards, adhesives and urea formaldehyde foam cavity wall insulation (UFFI); man-made timbers contain bonding agents that release formaldehyde. Whilst there are figures in existence for the levels of formaldehyde at which effects upon humans are detectable,[3] and that the level of

---

[2] Prior, Josephine. J., Paul B. Bartlett. *Environmental Standard - Homes for a Greener World*, Garston: Building Research Establishment, 1995, p. 19.

[3] The *Environmental Standard* summarises these as follows:

> The World Health Organisation reports the threshold of irritation of airborne formaldehyde to be 0.1 $mg.m^{-3}$ and that symptoms of irritation of the eye and throat occur at levels between 0.3 and 0.1 $mg.m^{-3}$ in healthy subjects. The odour detection threshold of formaldehyde is 0.06 $mg.m^{-3}$. The International Agency has classified formaldehyde as possibly causing cancer in human beings for Research on Cancer (IARC) but the evidence is not sufficient to enable the risk of cancer to be estimated.

formaldehyde in the air will be dependent upon two factors: the rate of emission and the rate of fresh air ventilation, because the emission rate cannot be predicted at the design stage, it is impossible to benchmark a minimum formaldehyde level through a benchmark ventilation rate.[4]

To overcome this, the *Environmental Standard* set down that should UFFI, particleboard or medium density fibreboard (MDF) be specified, then they should conform to the relevant British Standard; BS 8208, BS 5617 and BS 5618 in the case of UFFI, BS 5669 in the case of particleboard, and BS 1142 in the case of MDF. These standards limit the permissible levels of the free formaldehyde content for UFFI, and the permissible levels of extractable formaldehyde content for man-made timbers, and the methods of workmanship required of working with these materials.[5]

In terms of interior fixtures and fittings the *Handbook of Sustainable Building Materials*, based on the Dutch Environmental Preference Method, provides three alternatives for materials to be used, the first being the most preferred and the third the least, and also materials that are not recommended; all based on the environmental impact associated with those materials.[6] The EPM rates the use of chipboard and fibreboard for kitchen units as only its third preference, because of the pollution and formaldehyde emissions inherent to the bonding materials. For worksurfaces, chipboard with melamine facing is not recommended due to the pollution arising from the content of a large amount of bonding materials.

Whilst BS 5669 sets a maximum standard for the acceptable level of extractable formaldehyde content from particleboards of 25 mg per 100 g of board, a German standard sets an even lower acceptable formaldehyde content, of 10 mg per 100g of board.[7] There are particleboards available that release no formaldehyde content from the bonding agents (<2 mg.m^{-3}).

In terms of asbestos and paints with added lead, the *Environmental Standard* demanded that the materials specification show the absence of these materials. In view of the health risks associated with formaldehyde emissions, and the low recommendations made by the

---

[4] Ibid.
[5] The British Standards Institute. BS 5617: 1985 - Urea-formaldehyde (UF) foam systems suitable for thermal insulation of cavity walls with masonry or concrete inner and outer leaves; BS 1142: 1989 - Fibre building boards; and BS 5669: Part 2: 1989 - Particleboard.
[6] Anink, David, Chiel Boonstra and John Mak. *Handbook of Sustainable Building Materials*, London: James & James (Science Publishers) Limited, 1996.
[7] Prior, Josephine. J., Paul B. Bartlett. Op. Cit.

Environmental Preference Method for manmade boards, both because of the formaldehyde emissions and the pollution associated with the production of the bonding agents, it is proposed that the benchmark for formaldehyde emissions will also demand the absence of materials associated with the emission of formaldehyde, i.e. manmade timber, and urea formaldehyde foam insulation, which has precedent in the Residential Energy Efficiency Database.

In respect of wood preservatives the *Environmental Standard* demanded that no use is made of treated timber except where recommended by the relevant codes and standards, and that all preserved timber is industrially pretreated for finishing on site. The latter of these requirements means that treatment is conducted under controlled and supervised conditions, which ensures a standard of quality that are not always obtained on site, but also reduces the potential for solvent emission from treated timber into the building following completion.[8]

An alternative to using preservative treated timber is to specify species of wood with sufficient natural durability; however, there may be additional cost, engineering consequences and supply implications with some types.[9] Also, few of the species that have sufficient durability class ratings (I and II) are European, with the exception of robinia (acacia), Spanish chestnut and oak, and therefore, even if a sustainable source is specified, there will be a significant impact on the embodied energy in the material.[10] However, the

[8] Ibid.
[9] Ibid.
[10] Anink, David, Chiel Boonstra and John Mak. Op. Cit.

Environmental Preference Method states that, with careful specification and maintenance to control the moisture content, timber from Durability Class III can be used, which include deal, larch, cherry and Douglas Fir which have European sources.

An empirical study was made of a dwelling built to current standards by a national house builder, and was found to contain materials identified as unacceptable in the benchmark below. It was a specific intention in the design of Drawn Study 4, the Aire 8100 dwelling for Allerton Bywater, to create a dwelling that benefited the health of the inhabitants. Therefore it was designed so that materials with low toxicity potential would be used throughout the interior. The research has not been able to ascertain a comparative dwelling for this criterion, other than the standards proposed above which is therefore used.

For the benchmark of Quality of the Internal Environment: Indoor Pollution to innovate upon best practice, taken as that of the *Environmental Standard*, it is proposed that the 'urban house in paradise' will not use the following materials throughout the interior of the dwelling: medium density fibreboard (MDF), particleboard, chipboard, formaldehyde, lead based paints, preservative treated timber and urea- formaldehyde foam insulation. The benchmark of ventilation will propose a standard that is in advance of the requirement of CREED.

Methodology of Assessment

As the benchmark is based upon the exclusion of the use of certain material, rather than a permissible level of pollutants, the assessment will be based upon the following question. 'Is the interior of the dwelling free from the use of the following materials: medium density fibreboard (MDF), particleboard, chipboard, formaldehyde, lead based paints, preservative treated timber and urea- formaldehyde foam insulation?' Compliance with the benchmark will require the answer is 'Yes'.

Conclusion

Therefore, the proposed benchmark for the criterion of Quality of the Internal Environment: Indoor Pollution, seen in the context of the other comparative benchmarks of the typical speculative dwelling, best practice comparative and Drawn Study Five, is proposed in the table overleaf:

	Indoor Pollution
Typical UK speculative dwelling	No
European comparative: CREED	No
Drawn Study: 5	Yes
The 'urban house in paradise'	**Yes**

Quality of the Internal Environment: Indoor Pollution benchmark for the 'urban house in paradise'

3.26 Quality of the Internal Environment: Daylight

The provision of daylight in a dwelling is, of course, a necessity. However, providing levels of daylight that are above typical or minimum standards can have significant benefits, both in terms of sustainability and desire, as people tend to prefer an environment illuminated by daylight to an artificially illuminated one.

In terms of sustainability, the benefits can be twofold. Firstly, the increased provision of daylight can reduce the use of artificial light, and therefore create direct savings in fossil fuel consumption. Secondly, through the thoughtful increase of window size, and consideration of window location and orientation, more use can be made of passive solar gains to the dwelling, and thereby reducing space heating demand and further fossil fuel use. However, a balance needs to be struck. Even very high performance windows are not as thermally efficient as the walls or roof surface in which they are located, thus increasing their area also increases heat loss; therefore a balance needs to be established between solar gains and thermal losses. Also, increasing the widow size can lead to excessive solar heat gains; this can create problems of excessive heat, and therefore effect the comfort level of the internal environment.

The Building Research Establishment's *EcoHomes* recognises the value of daylight.[1] An attempt is made to maximise its use through awarding credit for designing the kitchen and habitable rooms to meet the daylight criteria of BS 8206: Part 2. The average daylight factor is a measure of the average interior illuminance compared with the external horizontal global illuminance, under overcast conditions, and is quantified as a percentage; as a method of measurement it has the advantage that it can easily be related to the area of the glazing.[2] The standards set for the minimum average daylight factors in dwellings permissible under the British Standard are: 1 percent in bedrooms, 1.5 percent in living rooms and 2 percent in kitchens.[3]

The average daylight factor of a space can be determined at the design stage by the following equation:[4]

---

[1] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.
[2] Littlefair, P. J. 'Average Daylight Factor: A Simple Basis for Daylight Design,' *BRE Information Paper IP 15/88*, Building Research Establishment, November 1988.
[3] British Standards Institute. *BS 8206: Part 2: 1992 - Lighting for Building Codes of Practice for Daylighting*, London: HMSO, 1992.
[4] Littlefair, P. J. Op. Cit.

$$DF\ (\%) = (M . W . \theta . T) / (A . (1 - R^2))$$

where, W = total glazed area of windows
A = total area of all room surfaces (ceiling, floor, walls, windows)
R = area-weighted average reflectance of the room surfaces
M = correction factor for dirt and glazing bars
T = glass transmission factor
θ = angle of visible sky

guide values for these variables are:[5]

R =	0.5
M =	1.0 for vertical glazing that can be easily cleaned
	0.8 for inclined glazing
	0.7 for horizontal glazing
T =	0.7 for double glazing
	0.6 for double glazing with low-emissivity coating
θ =	65° for vertical glazing

The values of the average daylight for the typical three bedroom semi-detached dwelling built by a national house builder have been measured using this methodology in order to determine a base standard. The outcome of the measurements is as follows:

Living spaces: 2.4 percent, kitchens: 1.5 percent, bedrooms: 1.6 percent.

This shows that, with the exception of the kitchen value, even the typical dwelling already achieves the standards set by *EcoHomes*. Therefore, if the matrix seeks to improve upon the standards of daylight in dwellings produced by the current house building industry, the benchmark will have to be set above that of BS 8206: Part 2, and, therefore, *EcoHomes*. This is an important point, as it demonstrates that not all of the standards that might be considered innovative are, in reality, pressing forward the standards of current practice. It is therefore necessary to consider all of the benchmarks of the matrix of criteria against both current practice and standards proposed as innovative by other sources, in order to determine what innovation will, in truth, demand.

The Drawn Studies completed in the first phase of the thesis can provide some input into what the potential standards of the matrix benchmark could be. In Drawn Study 2 – Glasgow: The Scale of the Individual Dwelling, the mean average daylight factors have been calculated as: Living spaces: 8.4 percent, kitchens: 7.6 percent, bedroom: 7.6 percent. At the Allerton Bywater Millennium Community competition, for Drawn Study 4 the mean average daylight factors for the dwelling types proposed have been calculated as summarised in the table below.

Dwelling	Mean Average Daylight Factor (percent)		
	Living spaces	Kitchen	Bedroom
2 Bed equivalent	5.75	-	3.6
3 Bed equivalent	4.5	2.0	3.4
4 Bed equivalent	3.5	1.7	3.1
Total mean	**4.6**	**1.9**	**3.4**

Average Daylight Factors for Drawn Study Four

Here the value for the kitchen is, as for the typical dwelling of the national house builder, below the standard of BS 8206: Part 2. In terms of making the best use of solar gain, there is a logic in placing habitable rooms towards the south, so that these benefit the most form the sun, and locating other spaces, such as kitchens and bathrooms, toward the north. If this trend is to be followed, even acknowledging the increasing role for the kitchen as a gathering space for the family, then benchmarking the kitchen daylight factor too high may result in larger glazing areas facing north, which will not benefit from solar gain and will contribute to increased heat loss, for reasons described above. The issue of the function of the space, and the implications this may have, will be considered when proposing values for the benchmarks.

A Huf Haus dwelling is used as a comparative of best practice. This is built by a timber frame dwelling built by a German company, which specifically intends to create well illuminated internal space through a generosity of glazed surfaces. The outcome of the measurements is as follows:

Living spaces: 4.0 percent, kitchens: 2.1 percent, bedrooms: 2.9 percent.

Standards of daylight for dwellings that are above that of BS 8206: Part 2, and therefore *EcoHomes*, have been proposed. Lynes writes,

> Experience indicates that if the average daylight factor exceeds about 5 percent the interior will look cheerfully daylit. If the average daylight factor drops below 2 percent, natural lighting alone will seldom be satisfactory and electric lighting is likely

[5] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. Op. Cit.
[6] Lynes, J. A. 'Daylight and Energy', in Roaf, S. and M. Hancock (eds). *Energy Efficient Building – A Design Guide*, Oxford: Blackwell Scientific Publications, 1992, p. 33.

to be in constant use.[6]

A daylight factor of 5 percent seems high for bedrooms, where the intrusion of daylight may be undesirable. Therefore, the benchmark of the 'urban house in paradise' will be based upon the values proposed by Lynes, but lowered to a value that has been developed through other sources, such as the European comparative dwelling.

Methodology of Assessment

The assessment of the benchmark will be based upon the standard equation for calculating the average daylight factor.

$$\text{Daylight factor (percent)} = (M \, . \, W \, . \, \theta \, . \, T) \, / \, (A \, . \, (1 - R^2))$$

where, W = total glazed area of windows
A = total area of all room surfaces (ceiling, floor, walls, windows)
R = area-weighted average reflectance of the room surfaces
M = correction factor for dirt and glazing bars
T = glass transmission factor
θ = angle of visible sky

Conclusions

Therefore, the proposed benchmark for the criterion of Quality of the Internal Environment: Indoor Pollution, seen in the context of the other comparative benchmarks of the typical speculative dwelling, best practice comparative and Drawn Study Five, is proposed in the table below:

	Mean Average Daylight Factor (percent)		
	Living spaces	Kitchen	Bedroom
Typical UK speculative dwelling	2.4	1.5	1.6
European comparative: Huf Haus	4.0	2.1	2.9
Drawn Study: 4	4.6	1.9	3.4
The 'urban house in paradise'	5	5	3.5

Ecological value benchmark for the 'urban house in paradise'

3.27 Quality of the Internal Environment: Ventilation and Air Tightness

> When I first took up my abode in the woods, my house was not yet finished for the winter, but was merely a defense against the rain... The winds which passed over my dwelling were such as sweep over the ridges of mountains, ... The morning wind forever blows, the poem of creation is uninterrupted.
>
> This frame, so slightly clad, was a sort of crystallisation around me, ... I did not need to go out doors to take the air, for the atmosphere within had lost none of its freshness.[1]

This quote by Thoreau, regarding his dwelling at Walden, epitomises the desirable contact between the interior of the dwelling and the environment that surrounds it. It is estimated that in developed countries, people spend on average 85 percent of their time indoors,[2] yet only relatively recently has attention begun to be paid to the air quality of the indoor environment and indoor pollution.

The quality of the internal environment of the dwelling will be affected both from within the dwelling, from pollutants emitted from building materials, and from the outside, as fresh or polluted air admitted through leakage or ventilation. The latter is, of course, particularly relevant in the context of the urban environment, where maintaining a high quality internal air quality may be at odds with connecting with the external environment. Research conducted in the United States of America has demonstrated a clear relationship between outdoor pollution levels and mortality rate. It concluded that, "fine-particle air pollution, or a more complex pollution mixture associated with fine particulate matter, contributes to excess mortality in certain U.S. cities".[3] This effect has also been proven for London.[4] Whilst a range of pollutants demonstrate a relationship between mortality and pollution level, it is particularly distinct for fine particulate matter; these arise primarily from the combustion of fossil fuels in transport, manufacturing and power generation.[5]

---

[1] Thoreau, Henry David. *Walden*, London: Everymans Library, 1974, p. 73.
[2] Wellburn, Alan. *Air Pollution and Climate Change: The Biological Impact*, London: Longman Scientific & Technical, 1994.
[3] Dockery, Douglas J. et al. 'An Association Between Air Pollution and Mortality in Six U.S. Cities,' *New England Journal of Medicine*, 9 December 1993, p. 1753.
[4] Schwartz, J. and A. Marcus. 'Mortality and Air Pollution in London: A Time Series Analysis,' *American Journal Epidemiol*, Volume 131, 1990.
[5] Dockery, Douglas J. et al. Op. Cit.

Air Tightness

The air tightness within and through a dwelling's fabric can significantly effect the energy consumption of that dwelling. In BRECSU's *General Information Report 39*, a review of ten examples of ultra-low-energy dwellings in the United Kingdom, one of the primary causes of poor energy performance of schemes within the United Kingdom was stated as unexpectedly high air leakage through the building envelope. Therefore, one route to improving energy performance would be to reduce air leakage, creating an almost sealed dwelling.

Structural infiltration is the uncontrolled passage of external air into a building through the fabric of its envelope. Vale and Vale consider that all authorities on low energy dwellings stress the importance of airtight construction;[6] heat loss through infiltration, can be one of the largest factors contributing to heat loss from dwellings.[7] The air tightness of a dwelling, reducing the structural infiltration of the envelope, is achieved through high quality in the design and construction of details. This would include consideration of, for example, the inclusion of an air-barrier membrane, continuity of wet finishes internally such as ensuring that wall plaster is brought right down to a floor screed, careful sealing of windows and doors into walls, and seals on all opening elements.

In an urban environment, for a healthy dwelling, the need could be argued for filtered air, and therefore for controlled ventilation; in addition, maintaining a healthy environment within a highly insulated and sealed environment could also favour the use of controlled ventilation. The use of mechanical ventilation to fulfill the above aims may appear to be at odds with low energy dwellings, due to the energy consumption of the system. However, through providing a relatively low controlled ventilation rate, the heat loss of space heat can be reduced significantly when compared with other ventilation methods, in particular if heat recovery is used in conjunction with the mechanical ventilation. With mechanical ventilation and heat recovery (MVHR) units, energy is consumed to drive the fans. The electricity consumption per unit of delivered fresh air can vary by a factor of three; in some cases, the electricity consumption of the unit can offset a substantial proportion of the space heating energy saved.[8]

---

[6] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.
[7] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998; and BRECSU. 'Review of Ultra-Low-Energy Homes - Ten UK Profiles in Detail,' *General Information Report 39*, London: HMSO, March 1996.
[8] BRECSU. 'Review of Ultra-Low-Energy Homes - Ten UK Profiles in Detail'.

In the *General Information Report 38*,[9] a review of 52 ultra-low-energy dwellings both in the United Kingdom and abroad, at least 63 percent of the dwellings had mechanical ventilation with heat recovery. Of the ones that did not, at least 42 percent had passive stack ventilation. Of the ten with the lowest quoted energy consumption, 80 percent had MVHR. The two that did not also had mechanical ventilation, one exhaust only, but the report did not specify whether or not heat recovery was included. Of the ten with the quoted lowest energy consumption, the air leakage rates ranged between 0.17 and 0.5 $ac.h^{-1}$ at 50 Pa; the dwellings with the highest quoted energy consumption figures in the same report, the air leakage ranged between 1.47 and 11.9 $ac.h^{-1}$ at 50 Pa. In its conclusions, *GIR 39* puts forward values of a relatively airtight dwelling by United Kingdom standards of 3 to 4 $ac.h^{-1}$ at 50 Pa, and for a very airtight dwelling, again by United Kingdom standards, as less than 1 $ac.h^{-1}$ at 50 Pa.

The comparable performance characteristics of the zero CO_2, zero heating and autonomous dwellings of *GIR 53* can be extended to include the air tightness requirements to achieve the standards proposed. The zero CO_2 dwelling would demand an air tightness of 3 $ac.h^{-1}$ at 50 Pa, and for the zero heating and autonomous standard a level of 1 $ac.h^{-1}$ at 50 Pa would be required.[10] In the case of the latter, with full mechanical ventilation and heat recovery of at least 60 percent efficiency, with additional 8000 mm^2 trickle ventilators fitted to windows would be required.[11]

In their report to the Joseph Rowntree Foundation, *Towards Sustainable Housing: Building Regulation for the 21st Century*,[12] Robert Lowe and Malcolm Bell approximate that naturally ventilated dwellings, the type of ventilation typical of most United Kingdom new build dwellings, have an air leakage in the region of 10 to 15 $ac.h^{-1}$ at 50 Pa. They state that,

> ... total energy use declines monotonically with envelope air leakage in dwellings with balanced mechanical ventilation, but reaches a minimum at a leakage somewhere between 2 and 3 $ac.h^{-1}$ at 50 Pa in dwellings fitted with continuous mechanical extract.[13]

Another source confirms that the approximate air tightness of the 'typical' dwelling built to

[9] BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, London: HMSO, February 1996.
[10] Evans, Paul of Building Research Establishment's Environmental Best Practice Division, at Sustainability in Building Design conference, University College Chester, 18 August 1999.
[11] BRECSU. 'Building a Sustainable Future - Homes for an Autonomous Community,' *General Information Report Number 53*, HMSO, October 1998.
[12] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.
[13] Ibid., p. 26.

current regulatory standards is in the region of 15 $ac.h^{-1}$ at 50 Pa. This source also proposes values of air tightness that would be required to achieve the zero CO_2, zero heating and autonomous dwelling standards of *GIR 53*; they are 3, 1 and 1 $ac.h^{-1}$ at 50 Pa respectively.[14] Despite the poor standard of air tightness produced by the majority of national house builders in the United Kingdom, some are attempting to improve the level of performance. For example, the Wimpey 'Superspec' dwellings, aimed to demonstrate that energy efficient measures improving upon those of the 1995 Building Regulations were practicable for incorporation in a house builder's pattern book, achieved an air tightness of 4.8 to 6.64 and 8.77 $ac.h^{-1}$ at 50 Pa.[15]

Lowe and Bell go on to propose that a limit on air leakage be included within revisions to the Building Regulations in the United Kingdom, to be subject to post completion test of between 5 and 10 percent of all new dwellings. A maximum limit is suggested of 10 $ac.h^{-1}$ at 50 Pa in the year 2000, reduced to 3 $ac.h^{-1}$ at 50 Pa in 2005.

Building regulation in Sweden already imposes stringent constraints on air tightness and ventilation with heat recovery.[16] The Swedish standard for air tightness in the current edition of their building regulations is 0.8 $l.s^{-2}$ per m^2 for dwellings;[17] for a typical three bedroom semi-detached dwelling with a floor area of 84 m^2, this equates to an air tightness of 2.4 $ac.h^{-1}$ at 50 Pa.

As a criterion of the 'urban house in paradise' air tightness also contemporary relevance. The proposed revisions to the Building Regulations in England and Wales, due to come into effect in 2001 contain air leakage targets. Under the new Regulations, Building Control Officers will be able to require testing of buildings over 1,000 m^2, although individual dwellings as samples may also become subject to mandatory air tightness testing.[18] The standard has been proposed at 10 $m^3.h^{-1}.m^{-2}$ of the building envelope at 50 Pa, which is considered to be twice current best practice; this may be progressively reduced to 5 $m^3.h^{-1}.m^{-2}$ in 2002 and 3 $m^3.h^{-1}.m^{-2}$ in 2007.[19] For a typical semi-detached dwelling with a floor area

---

[14] Evans, Paul of Building Research Establishment's Environmental Best Practice Division, at Sustainability in Building Design conference, University College Chester, 18 August 1999.
[15] BRECSU. 'Application of Energy Efficient Pattern Book Housing', Good Practice Guide Case Study 306, London: Construction research Communications Limited, October 1996.
[16] Lowe, Robert and Malcolm Bell. Op. Cit.
[17] Swedish Board of Housing, Building and Planning. *Building Regulations BBR 94 - BFS 1993:57, with Amendments BFS 1995:17, BFS 1995:65*, Boverket, 1995.
[18] Bunn, Roderic. 'Pressure Tests and Energy Meters in *Part L* Revamp', *Building Services Journal*, July 2000.
[19] Department of the Environment, Transport and the Regions. *The Building Act 1994 – Building Regulations - Proposals for Amending the Energy Efficiency Provisions – A Consultation Paper Issued by Building Regulations Division*, London: HMSO, June 2000.

of 84 m^2,[20] the total external envelope can be approximated as 165.6 m^2.[21] At 10 $m^3.h^{-1}.m^{-2}$ this would equate to an air change rate of 1,656.4 $m^3.h^{-1}$. The volume of the example dwelling can be approximated as 201.6 m^2, which equates to an air tightness value of 8.22 $ac.h^{-1}$ at 50 Pa. The proposed values for 2002 and 2007 would be 4.11 and 2.46 $ac.h^{-1}$ at 50 Pa respectively. These are a significant improvement on current practice, and are in line with the values proposed by Lowe and Bell.

BREEAM/New Homes, a previous issue of the *EcoHomes*, contains a value for air tightness. This is based either on the inclusion of set construction techniques to ensure air tightness of the fabric, such as draught seals being fitted to windows and doors, and the sealing of holes in the airtight structure where services enter or leave the dwelling, or if a commitment is made to post completion testing to a set standard. The post completion value required for compliance is 7 $ac.h^{-1}$ at 50 Pa for mechanical ventilation, and 9 $ac.h^{-1}$ at 50 Pa for passive stack ventilation; the basis for these values comes from the Electricity Council's Medallion 2000 Award scheme, which calls for an air tightness level of 7 $ac.h^{-1}$ at 50 Pa. The *BRE Housing Design Handbook* also proposes values for the air tightness of new dwellings. As one would expect, it is recommended is that the dwelling is as airtight as possible; a maximum mean background infiltration rate of 0.2 $ac.h^{-1}$ is proposed.[22]

Increasing the level of air tightness, to reduce space heating losses, cannot be considered in isolation from the ventilation of the dwelling, as ventilation is a necessity for a healthy internal environment. If the air leakage of new dwellings is to be significantly reduced, then alternatives to the option of natural ventilation are likely to be needed, as this method demands an air leakage in the region of 10 to 15 $ac.h^{-1}$ at 50 Pa.

Like the built thermal performance of the fabric, the air tightness of the dwelling when built depends to a great extent on the quality of construction, and is accurately measurable only through post completion testing. Therefore, the importance of the relationship between design and construction becomes even more pivotal to achieving the desired performance standards in the completed dwelling, placing more emphasis and procuring the right relationship between the concerned parties.

A table of the air tightness of the dwellings considered in *GIR 38* is shown overleaf. These benchmarks as accompanied with the required performance of the proposed regulations for

[20] This is derived from the Space Standards: Area analysis.
[21] This is based on a footprint of 42 m^2 with a length to width ratio of 2:1; the roof pitch is considered as 50 degrees and the ceiling height as 2.3 m.
[22] *BRE Housing Design Handbook*, Garston: Building Research Establishment, 1987.

England and Wales and the existing regulation for Sweden. The typical value of a dwelling in the United Kingdom is included as a control value.

Dwelling	Air Tightness (ac.h^{-1} at 50 Pa)
Typical UK dwelling	10 to 15
Proposed value in 2001 Part L Regulations	8.2
Proposed value in 2001 Part L Regulations	4.1
Proposed value in 2001 Part L Regulations	2.5
Swedish Regulation, SBN-80	2.4
Lower Watts House	3.6
Winslow, Milton Keynes	1.9
Lifestyle 2000, Milton Keynes	1.7
Two Mile Ash, Milton Keynes	1.5
Duncan House, Canada	0.5
Solar House, Friberg	0.3
Autonomous House, Southwell	0.2
Passiv Haus, Darmstadt	0.2
House B, Hjortkaer	0.2
Zero Energy house, St Gallen	0.17

Regulatory and comparative air tightness performance of selection of dwellings[23]

In his analysis of low energy dwellings, Stephen Carpenter compares the air tightness of a range of dwellings from around the world. This data can be used to provide examples of European best practice. These are summarised in the table overleaf.

The innovative dwellings built as a part of the Expo 2000 project in Hanover, the energy consumption of which is considered in Energy Consumption: Inhabitation, refer to Annexe 3.16, provides a more contemporary comparative of an urban dwelling project for 142 low-rise flats for 500 inhabitants. The modeling of the development established an estimated air tightness standard of 0.4 ach.h^{-1} at 50 Pa.[24] This is added to the list of comparatives overleaf.

[23] BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*,
[24] Bellew, Patrick and Jochen Kauschmann. 'Hanover Fare', *Building Services Journal*, August 2000.

Dwelling	Air Tightness (ac.h^{-1} at 50 Pa)
IEA 5 Solar House, Finland	1.0
Low Energy House, Finland	1.5
Flair Homes Energy Demonstration, Canada	0.4 to 0.8
Innova House, Canada	1.03
Waterloo Region Green Home, Canada	0.8
Brampton Advanced House, Canada	0.9 to 1.35
CMHC Healthy House, Canada	2.0
Ingolstadt, Halmstead, Sweden	1.4
Tubberupvaenge II, Denmark	1.5
Lotissement Solaire Aurore, France	0.3
Castricum Autonomous Solar House, Holland	0.2
Pilot R-2000 Homes, Japan	0.2
OPTIMAR: The Energy Answer, USA	0.2
Expo 2000, Hanover	0.4

Comparative air tightness performance of selection of dwellings[25]

As the air tightness of the dwelling is critically related to the energy consumed during inhabitation, the benchmark of the European best practice comparative dwelling will be the same as that used for the Energy Consumption: Inhabitation, so that comparability is maintained between these closely interrelated criteria; it is joint second lowest, and only 0.03 ac.h^{-1} at 50 Pa above that of the lowest.

In terms of the Drawn Study benchmark, a value of the air tightness cannot be given, as no dwelling have been built and therefore a pot completion test is impossible. However, a value can be proposed on the basis of the target that is assumed will be achieved so that the energy consumption target will be met. The air tightness benchmark aimed toward is 2.0 ac.h^{-1} at 50 Pa.

Methodology of Assessment

Air tightness can only be assessed accurately by post completion testing; therefore the proposed value will be a design benchmark for the architect and contractor to achieve through high quality detailing and construction.

[25] Carpenter, Stephen. *Learning from Experiences with Advanced Houses of the World*, Sittard: Centre for the Analysis and Dissemination of Demonstrated Energy Technologies, 1995.

Conclusion

Therefore, the proposed benchmark for the criterion of Internal Quality of the Environment: Air Tightness, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative and Drawn Study Five, is proposed in the table below:

	Air Tightness (ac.h^{-1} at 50 Pa)
Typical UK speculative dwelling	> 10 to 15
European comparative: Passiv Haus	0.2
Drawn Study: 5	2.0
The 'urban house in paradise'	**0.17**

Internal Quality of the Environment: Air Tightness benchmark for the 'urban house in paradise'

Ventilation

There is a distinction between air tightness, which is a measure of the rate of air leakage through the fabric of the dwelling, and the ventilation rate as provided by, for example, mechanical ventilation with heat recovery or passive, natural ventilation; although air leakage will be a part of the total ventilation of the dwelling. Within a relatively airtight dwelling, as proposed by the 'urban house in paradise', in order to maintain a healthy internal environment there is the need to ensure a cycle of ventilation through the provision of fresh air. The value of the rate of air changes needs to create a balance between the replacement of stale internal air with fresh external air, and heat loss incurred through the process of removing warm internal air and replacing it with cooler external air. Even if heat exchangers are utilised in a mechanical system to preheat the incoming air with the extract, if these are not 100 percent efficient heat loss will still occur, and also they will consume energy through their operation.

Like air tightness, heat loss through ventilation, can be one of the largest factors contributing to heat loss from dwellings[26] and therefore can have a significant influence on the energy consumption of the dwelling.

Therefore, the benchmark for the rate of ventilation to the 'urban house in paradise' should be sufficient to ensure the provision of a healthy internal environment, but not cause unnecessary heat loss. The ventilation required in order to maintain a healthy internal environment in a typical dwelling would be a whole house rate of 0.5 $ac.hr^{-1}$. This is the baseline assumption in the SAP assessment method, based upon empirical evidence.[27] The Genvex unit, a combined domestic hot water and mechanical ventilation system with heat recovery unit determines the ventilation rate of the dwellings at Allerton Bywater; this supplied pre warmed fresh filtered air at a rate of 0.6 $ac.hr^{-1}$.

The *BRE Housing Design Handbook* also proposes a value for whole house ventilation rate using MVHR. The proposed value is 0.5 to 1.0 $ac.hr^{-1}$. This is also the standard demanded by *BREEAM/New Homes*. In addition, it is recommended that the total air supply flow rate be set at 90 percent to 95 percent that of the extract rate. This is to depressurise the interior of the dwelling slightly, thereby preventing the movement of moist air from the living spaces

[26] Vale, Brenda and Robert. Op. Cit.
[27] Department of the Environment, Transport and the Regions. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, London: Construction Research Communications Limited, 1998.

into the structure, where there could be a risk of interstitial condensation.[28] Creating a negative air pressure inside the dwelling will also have the effect of drawing cold external air into the dwelling as draughts; however, to a great extent this should be overcome providing that the dwelling is sufficiently airtight.

The CIBS *Building Energy Code* states that a mechanically ventilated building should provide air at a rate of 5 litres per second per person;[29] this equates to 18 m^3 per hour per person. The space standards analysis in the Space Standards: Volume benchmark gives a value of 39.5 m^3 per person for a 5 person typical three bedroom dwelling, therefore 197.5 m^3 in total. At the rate of demand of 5 litres per second per person, five people would require 90 m^3 per hour; an air change rate for the typical dwelling of 0.46 $ac.hr^{-1}$.[30] If the dwelling were larger than this, which can be expected if the Space Standards benchmarks are adopted, this value will be lower.

Marshall and Argue state of ventilation of Canadian dwellings that, "Most potential air-quality problems disappear when the air change rate is 0.2 $ac.hr^{-1}$ and greater. However, humidity control requires a rate of 0.3 $ac.hr^{-1}$ or more."[31] This would suggest that the value of 0.46 determined above could be reduced to as low as 0.3 $ac.hr^{-1}$. However, one reason for this lower value may be that dwellings in Canada are typically larger than their equivalent in the United Kingdom.

In his analysis of low energy dwellings, Stephen Carpenter compares the ventilation rate of a range of dwellings from around the world; a selection of these is shown in the table overleaf. This data is used to establish the comparative dwelling of European best practice.

---

[28] *BRE Housing Design Handbook*, Garston: Building Research Establishment, 1987.
[29] Chartered Institution of Building Services. *Building Energy Code: Part One*, London: Chartered Institution of Building Services, 1980.
[30] The calculation used here is adapted from one given in Vale, Brenda and Robert. *The New Autonomous House*, London: Thames & Hudson, 2000.
[31] Marshall B. and R. Argue. *The Super-Insulated Retrofit Book*, Toronto: Renewable Energy in Canada, 1981; in Vale, Brenda and Robert. Op. Cit.

Dwelling	Ventilation (ac.h^{-1})
IEA 5 Solar House, Finland	0.6
Low Energy House, Finland	0.5
Flair Homes Energy Demonstration, Canada	0.5
Innova House, Canada	0.37
Waterloo Region Green Home, Canada	0.35
Brampton Advanced House, Canada	0.23
CMHC Healthy House, Canada	0.25
Ingolstadt, Halmstead, Sweden	0.45
Tubberupvaenge II, Denmark	0.45
Lotissement Solaire Aurore, France	0.6
Castricum Autonomous Solar House, Holland	0.45
Pilot R-2000 Homes, Japan	0.45
OPTIMAR: The Energy Answer, USA	0.36

Comparative ventilation rate of selection of dwellings[32]

On the basis that the volume of the dwelling given in the example for the CIBSE recommendation is likely to be at least the volume of the 'urban house in paradise', as it is based on the tight space standards of a national house builder, the benchmark for the ventilation rate of mechanically ventilated dwellings will be 0.45 ac.hr^{-1}. The SAP assessment contains steps to evaluate the ventilation rate of a dwelling.[33] The methodology contains a constant value of the assumed minimum value of an acceptable ventilation rate; it is proposed that should the ventilation, by mechanical or natural means, fall below this threshold the inhabitants will open windows to increase the air flow into the dwelling.[34] This constant is 0.5, and therefore closely comparable to that proposed for the 'urban house in paradise'.

Methodology of Assessment

The Energy Consumption: Inhabitation benchmark is established using the SAP assessment. As the benchmark of ventilation rate will have a direct impact upon the energy consumption, and the SAP assessment contains steps for the evaluation of the ventilation

[32] Carpenter, Stephen. *Learning from Experiences with Advanced Houses of the World*, Sittard: Centre for the Analysis and Dissemination of Demonstrated Energy Technologies, 1995.
[33] Department of the Environment, Transport and the Regions. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings.*
[34] Personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.

rate, it is concluded to use the relevant steps in the SAP methodology to calculate the performance against this benchmark. For mechanical ventilation the value could be clarified by the volume of the dwelling divided by the systems ventilation rate.

The energy lost through ventilation can also be determined using the benchmark of air change rate, the volume of the dwelling, and the heat capacity of air.

Conclusion

Therefore, the proposed benchmark for the criterion of Internal Quality of the Environment: Air Tightness, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative and Drawn Study Five, is proposed in the table below:

	Air Tightness (ac.h^{-1} at 50 Pa)
Typical UK speculative dwelling	> 10 to 15
European comparative: Ingolstadt	0.45
Drawn Study: 5	0.6
The 'urban house in paradise'	**0.45**

Internal Quality of the Environment: Ventilation benchmark for the 'urban house in paradise'

3.28 Reduction and Recycling of Construction Waste

Waste arising from the construction and demolition industry amounts to 7 percent of the total annual waste arising in the United Kingdom.[1] There is a proportion of the total waste from construction sites that is unavoidable, sometimes referred to as the 'natural' waste. As it is not technically feasible to prevent all construction waste, it would be impossible to propose the ideological benchmark of reducing the incidence of waste to zero. However, studies show that the amount of material that is wasted is typically much higher than the level that the construction industry assumes in its allowances for wastage in estimating.[2] A number of the precedents and statistics under the criterion of Deconstruction and Demolition: Recycling of Materials is also relevant to construction waste, although these will not be re-iterated here.[3]

The benchmark set for this criterion can be achieved both through the reduction of the quantity of waste that occurs, and also through ensuring that any waste that does occur is recycled wherever feasible. Achieving the benchmark reduction in terms of the occurrence of waste will be a site management issue, and will include communicating the importance of minimising waste to site personnel, contractor employees and sub contractor employees. This will also be the case for ensuring that any waste that occurs is, as far as possible, recycled; this will require the provision of suitable containers, and the communication of the purpose and importance of using these receptacles.

In a typical site, it is estimated that 10 percent of the materials delivered to site will become waste.[4] The benchmark will be measured in terms of the reduction of this value; this could be achieved in two ways, either through the reduction of its incidence, or through recycling any waste that does arise, or a combination of the two. This value is substantiated by the Sustainable Construction Unit of the Building Research Establishment.[5]

The increased use of standardisation and prefabrication will also help contribute to achieving this benchmark. For example, the use of standard modules will reduce the wastage that arises through off-cuts. Within a factory environment waste can be more effectively controlled and minimised. The waste that occurs on site through poor storage of materials can be controlled and eradicated within a factory, as long as the correct measures are in place

---

[1] Madden, Pauline. *Sustainable Waste Management*, unpublished BSc Construction Management thesis, Liverpool John Moores University, 1997.
[2] Skoyles E. R. and John R. Skoyles. *Waste Prevention on Site*, London: Mitchell, 1987.
[3] Refer to Deconstruction and Demolition: Recycling of Materials criterion, Annex 3.6.
[4] Skoyles E. R. and John R. Skoyles. Op. Cit.
[5] Personal communication with Jane Anderson, Consultant at the Centre for Sustainable Construction of the Building Research Establishment, 13 January 2000.

to ensure that prefabricated elements are correctly stored and handled when delivered to site.

For the millennium community at Allerton Bywater the benchmark of reducing construction waste by 50 percent throughout the supply chain has is proposed, and therefore reducing construction waste to 5 percent. It is envisaged that this will primarily be achieved through precision construction technologies using off site prefabrication.

In Europe recycling rates are much higher. In Denmark, for example, a rate of 80 percent is achieved for the recycling of all construction waste.[6] This can be used as a comparative benchmark of best practice, based upon the typical waste that arises through construction.

The reduction of on site waste through recycling has precedent within the United Kingdom also. At Chiswick Park office development in Stanhope, designed by the Richard Rogers Partnership, the waste reduction strategy included 160 wheelie-bins across the site for the segregation of construction waste at source. The percentage of waste arising is summarised in the following table.

Material Type	Percentage of Waste
Packaging	34.1
Plaster and cement	12.0
Insulation	11.4
Timber	11.2
Miscellaneous	7.6
Metal	4.9
Plastic	4.1
Concrete	3.3
Ceramic	0.2

Construction waste arising by percentage at Chiswick Park

The Greenwich Millennium Village development has also set a target for reducing construction waste arising on site of 50 percent over 6 years. Through continually measuring the waste that arises a strategy is evolved and developed for its management and

[6] McLaren, Duncan, Simon Bullock and Nusrat Yousuf. *Tomorrow's World - Britain's Share in a Sustainable Future*, London: Earthscan Limited, 1998.

evolving the management strategy, which ranges from the general awareness of workers on site to specific action for specific materials, such as the separation and storage of metal off-cuts on site. An overview of the waste composition arising on the GMV site is given in the table below.

Material Type	Percentage of Waste
Timber	32.9
Miscellaneous	18.0
Concrete	17.9
Plastics	16.7
Packaging	8.3
Metals	3.3
Insulation	1.4
Plaster and cement	1.1
Ceramic	0.0

Construction waste arising by percentage at the Greenwich Millennium Village

The 'urban house in paradise' benchmark value proposed, that construction waste should be a maximum of 2.5 percent of the material delivered to site, this reflects the amount of material that potentially could be recycled that typically arises in construction waste.[7] For example, the wastage rate of bricks is around 9 percent; it is recongised that the substantial losses that occur due to incorrect handling could be minimised with due care, and therefore education and management. At the work face, cutting also accounts for a significant wastage, and much of this has to do with design waste, which could be reduced through standardisation.[8] Therefore the benchmark could be achieved through the combination of two methods; firstly, the actual quantity of waste arising could be reduced, and secondly the natural waste that is unavoidable can be recycled to as greater extent as possible.

The benchmarked reduction also equates, coincidentally, to a Factor Four reduction in material waste.

[6] McLaren, Duncan, Simon Bullock and Nusrat Yousuf. *Tomorrow's World - Britain's Share in a Sustainable Future*, London: Earthscan Limited, 1998.
[7] Skoyles E. R. and John R. Skoyles. Op. Cit.
[8] Ibid.

Methodology of Assessment

Whilst targets and methods for achieving these targets can be established at the design stage, the assessment of the construction waste arising can only be carried out during and after the construction of the dwelling. The level of waste will be determined as the percentage of the quantity of material used within the dwelling and the total quantity of materials that are delivered to site, minus the quantity that has been recycled.

It is impossible to predict a generic numerical value the quantity of materials that will be in a dwelling, as the 'urban house in paradise' could be at once both a one person flat or a four bedroom terraced dwelling. For the benchmark of the quantity of construction waste that is to be reduced or recycled arising from the process of demolition, it will be necessary to use a percentage. Once this benchmark is applied to a particular dwelling, or even dwelling type, it can then be translated into a quantitative value if necessary.

Conclusion

Therefore, the benchmark standard for the Recycling and Reduction of Construction Waste, in the context of comparable standards, is: proposed in the table below:

	Construction Waste (percent)
Typical UK speculative dwelling	10
European comparative: Denmark	2
Drawn Study: 4	5
The 'urban house in paradise'	**2.5**

Recycling and Reduction of Construction Waste benchmark for the 'urban house in paradise'

3.29 Recyclability of Building: Adaptability

The ability of a dwelling to adapt and be reconfigured is of benefit to the potential lifecycle of that dwelling, in terms of its *useful* lifecycle, as opposed to its *material* lifecycle, which will both have an impact on the actual life span. Prolonging the useful lifecycle by creating the dwelling so that it can adapt to the unforeseen, changing needs or inhabitation patterns will, if it prevents the destruction of a dwelling that is no longer considered useful, maximise the use of energy and materials embodied within the fabric of the dwelling that remains after it has been reconfigured. This is one way in which the Design Life Span benchmark can be achieved.

One of the most notable examples of the adaptable urban dwelling is the Georgian terraced dwelling, a component of the grain of many cities within the United Kingdom. As a type, they demonstrate how a dwelling can be adapted into a new configuration of one dwelling, or several dwellings when converted into flats; they can also be adapted to accommodate other functions, such as offices, surguraries, shops and cafés. The reason for the inherent flexibility of the Georgian terraced dwelling is due to the size and proportion of the rooms, both in plan and in section, which make them suited to accommodating a range of functions; and the layout of these spaces around the staircase.

The ability of spaces to adapt to the unforeseeable changes in patterns of habitation, speaking both singularly of a particular dwelling, and plurality of the culture of changing habitation patterns and rituals, is increasingly becoming an area of innovation in housing design. It is a prototypical urban problem. Adaptability can extend beyond the individual dwelling, to become an adaptable block, where individual units can be absorbed to create larger dwellings. John Habraken notably developed the latter philosophy of adaptability in the 1960s.[1] Habraken's philosophy was to end the monotony of mass housing through the provision of housing as 'supports and shells'. The support structure enabled dwellings to be built within the structure independently of each other.

> A support structure is a construction which allows the provision of dwellings which can be built, altered and taken down, independently of the others.[2]

Habraken's philosophy has recently become a contemporary field of innovation. The housing proposed for the Greenwich Millennium Village in London, designed by a team led

[1] Habraken , John N. (translated into English by B. Valkenburg). *Supports: An Alternative To Mass Housing*, London: The Architectural Press, 1972.
[2] Ibid., p.59.

by the British architectural practice Hunt Thompson Associates in association with the Swedish architect Ralph Erskine, sought to,

> ... bring about a revolution in the concept of procurement and construction of the home in order to facilitate choice and adaptability.[3]

The methodology that the GMV team aimed to achieve this ambition was through modular construction. Internal panels within the dwelling were all non load-bearing, and could be removed through a mechanical fixing at the top and bottom of each 1200mm panel. Furthermore, the separating walls and floors between adjoining units could be removed, so that a dwelling could expand into the unit either side or above or below, as they became available. The principle was based on the concept that an inhabitant should not have to move from their dwelling because their circumstances, such as family size, change.

Adaptability emerged as a parameter to be included in the matrix of criteria that define the 'urban house in paradise' during Drawn Study Two, considering the potential flexibility of an urban building. The commercial units and the dwellings were intended to be as flexible as possible, with long spans between load-bearing structure. The House in House concept of the dwellings explored the way in which different patterns of use can be accommodated within the dwellings proposed, in ways that leave each of the urban elements spatially coherent. The traditional 'Japanese lunch box,' four standard enclosures each filled with a different filling, provide an impetus for the resolution of the relationship between generic urbanity and personal acts of urban dwelling. There was a potential of 12 different permutations of dwellings within the 32 enclosures created.

The benchmark could determine to what extent the form and construction of the dwelling is designed facilitate the potential adaptability of the interior to accommodate new functions or inhabitation patterns in the future. The issue then becomes how to quantify the degree of potential adaptability inherent within the dwelling. In terms of, for example, the internal divisions within a space, this could be a measure of the proportion of non load-bearing partitions to the total number of internal partitions. In Drawn Study Number Four, Allerton Bywater - The Individual Dwelling, the decision was made to minimise the number of internal load-bearing partitions; only four of the initial twelve types had internal load-bearing structure and the rest had none. This would both maximise choice in the initial layout, to suit the initial inhabitants preferences, and to maximise the potential adaptability of the dwelling the future.

---

[3] Taylor, David. 'Setting the Agenda for Future Urban Development,' *The Architects Journal*, 26 February 1998.

under development, which is aimed at a variety of building types, has adaptability as one of its criteria of assessment for multi-residential residential buildings. The sub-criteria used to determine the degree of adaptability qualitatively are:[4]

- Adequacy of floor to floor height for major changes in use.
- Appropriateness of core and structural member location for major changes in use.
- Potential for future upgrade of building envelope thermal performance.
- Capability for future change of energy supply.
- Ease of changing dwelling unit layouts for changing household requirements.

The Building Research Establishment's *EcoHomes* also includes the adaptability of a dwelling to respond to changing circumstances as a criterion that may be considered over and above those in the assessment, but this does not form a part of its overall evaluation.

The benchmark of the adaptability of a dwelling will need to be a measure of the degree of potential adaptability inherent within it. In terms of the interior, this requires devising a means of assessing the inherent adaptability of the internal spaces of the dwelling, both in plan and in section. This will be affected both by the form and proportion of the spaces, and the nature of the divisions within or between them, establishing whether they are load-bearing or not. The latter could be expressed as a percentage:

(Number of internal load-bearing walls/ total number of internal walls) x 100

An alternative methodology would be to use a quantitative benchmark, which would express the requirement that, where spans permit, there are no internal load-bearing partitions. This will maximise the potential adaptability of the interior space. As it is a specific intention of the thesis to propose quantitative, dimensional benchmarks the latter method has been selected.

To establish the benchmark performance of a typical dwelling, a number of the standard house plans for a national house builder were studied.[5] The benchmark was determined on the basis of the mean number of load-bearing internal partitions.

The Jungerhalde row housing in Konstanz, Germany, by Schaudt Architekten is used as a benchmark of a comparative dwelling of European best practice. This project is the outcome

---

[3] Taylor, David. 'Setting the Agenda for Future Urban Development,' *The Architects Journal*, 26 February 1998.
[4] Cole, Raymond J. and Nils K. Larsson. 'GBC '98 and GB Tool: background', *Building Research and Information*, Volume 27 Number 4/5 1999, p.229.

of a competition in low-cost row housing. The main living space is typically on the first floor of the three storey blocks, with children's or guest spaces under. The top floor usually contains the principal bed space, although in one dwelling this has been converted into a study, and another floor inserted to create a small sleeping space.

The brick party walls at 6 metre centres and basements are the only forms of wet construction in the terrace. Between the walls, the horizontal structure is of standard galvanised steel members, which are bolted together and braced by tie rods. The floors are composed of larch planking laid over steel joists. The industrial components are unusually conducive to their domestic application. The floors can be cut back to create voids. The construction disciplines of the standardised systems ensures that there is an overall rhythm of consistency, but the system has also facilitated the creation of diversity and individuality both in the interior of the dwellings, in response to the individual needs of the inhabitants. The free span interior constructed in industrialised elements means that the dwelling is highly suitable to adaptation.

The Flexibo housing development is the closest that Denmark has come to realising the concept of mutability of the dwelling. Its innovation lay primarily in the internal flexibility of the units, made feasible through a system of light partitions that could be arranged and re-arranged as though furniture.

Methodology of Assessment

Therefore the quantification of the benchmark value of adaptability is a measure the nature of the divisions within the dwelling, establishing whether they are load-bearing or not. This will also include load-bearing elements, such as columns and piers, although it is recognised that these would not impinge upon the potential adaptability of the dwelling to the same extent of load-bearing walls. These elements can be established from the design drawings. The benchmark can be measured by the following equation.

Number of internal load-bearing walls/ total number of internal walls

[5] Standard house plans of the Ambassador, Embassy, President and Statesman ranges, Barratt Design Group.

Conclusion

Therefore, the proposed benchmark for the criterion of Recyclability of the Dwelling: Adaptability, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative and Drawn Study 4, is proposed in the table below:

	Number of internal load-bearing elements
Typical UK speculative dwelling	0.8
European comparative: Jungerhalde	0
Drawn Study: 4	0
The 'urban house in paradise'	**0**

Recyclability of Building benchmark for the 'urban house in paradise'

3.30 Space Standards: Area

In order to propose new, innovative benchmark standards, first it is necessary to determine the existing standards of the contemporary housing construction industry. In terms of space standards this involved an extensive analysis of the internal space standards of products of a national house builder and national housing association, based on their typical house plans. The analysis focussed upon three criteria: typical area (m^2), typical volume (m^3), and space use, as a percentage of the total floor area. The latter served to determine the proportions of the area of the dwelling attributed to the various functions of habitation, and identify preferences and tendencies in space use within the dwelling. These figures, summarized in the table overleaf, provide an initial base figure from which to determine the benchmark value of internal space standards within the generic 'urban house in paradise'.

It was a specific intention in the winning submission of the Allerton Bywater Millennium Community Competition to increase the area and volume of the dwellings over that typically provided by national house builders. Therefore in Drawn Study 4, these figures provided the basis from which ten percent was added to the area, to create a more desirable dwelling. The additional cost was accounted for as a part of the savings made through rational, standardised, construction.

As a continuation of the space standards analysis, the typical products of the national house builder and national housing association were analysed again. This time the aim was to determine the mean value of dwelling area per inhabitant for each house type, and then to determine the overall mean dwelling area per inhabitant for all house types. This analysis, based on the measure of the mean net floor area[1] divided by the maximum number of inhabitants the dwelling is designed to accommodate during typical occupancy, can be summarised in the subsequent following table; the maximum and minimum values are also shown, to demonstrate the range of values.

[1] *Net floor area* is sum of the area of all the floors enclosed by the external walls; it includes the area occupied by partitions and the area taken up the staircase (if appropriate) on each floor.

House Type	**Int Area**	**Int Vol**	Lounge	Kitchen	Dining	B'fast	Study	Family	**Liv'g T**	Bed 1	Bed 2	Bed 3	Bed 4	Bed 5	Bed 6	**Bed T**	Circ	Utility	Bath	WC	En-S	**Clse T**	Airing	Store	**St T**
National House Builder																									
1B Min	45.2 m.sq	108.5 m.cu	25	11	10	-	-	-	46	26	-	-	-	-	-	26	2	-	8	4	-	8	1	1	2
1B Mean	45.3 m.sq	108.7 m.cu	34	15	10	-	-	-	52	27	-	-	-	-	-	27	7	-	9	4	-	31	1	4	5
1B Max	45.4 m.sq	109.0 m.cu	38	19	10	-	-	-	57	27	-	-	-	-	-	27	13	-	10	4	-	14	1	6	7
2B Min	51.5 m.sq	123.6 m.cu	23	9	9	7	-	-	43	16	11	-	-	-	-	32	8	-	6	3	4	6	1	2	1
2B Mean	61.0 m.sq	146.4 m.cu	27	11	10	8	-	-	45	18	14	-	-	-	-	33	11	-	7	3	4	8	2	3	4
2B Max	67.6 m.sq	162.2 m.cu	33	16	10	9	-	-	49	22	17	-	-	-	-	33	13	-	8	3	4	10	2	4	6
3B Min	64.7 m.sq	155.3 m.cu	17	7	8	4	-	-	32	11	10	6	-	-	-	27	7	3	4	2	3	6	1	1	2
3B Mean	81.8 m.sq	196.3 m.cu	22	10	9	5	-	-	40	14	12	7	-	-	-	33	12	4	5	2	5	12	1	2	3
3B Max	105.7 m.sq	253.7 m.cu	32	14	11	5	-	-	44	16	15	12	-	-	-	39	19	5	6	3	7	16	1	7	8
4B Min	82.1 m.sq	197.0 m.cu	11	7	7	3	4	5	31	10	8	5	5	-	-	30	8	2	2	1	2	10	0.5	1	1
4B Mean	125.1 m.sq	300.2 m.cu	17	10	8	5	4	6	38	12	10	8	6	-	-	36	11	3	4	2	4	12	1	1	2
4B Max	173.0 m.sq	415.2 m.cu	20	12	11	6	6	6	44	15	13	12	8	-	-	42	17	4	7	2	7	13	1	3	4
5B Min	154.7 m.sq	371.3 m.cu	12	6	8	5	4	4	33	9	7	7	4	4	6	35	11	2	2	1	4	9	0.5	1	1
5B Mean	181.0 m.sq	434.4 m.cu	15	7	8	5	5	5	38	10	8	8	6	4	6	38	12	3	2	1.5	4.5	11	0.5	1	1.5
5B Max	197.4 m.sq	533.0 m.cu	17	9	10	5	8	5	41	11	9	9	7	5	6	43	13	3	3	2	6	13	1	2	2.5
National Housing Association																									
1B flat	51.0 m.sq	122.4 m.cu	31	15	-	-	-	-	46	26	-	-	-	-	-	26	11	-	9	-	-	9	1	7	8
2B flat	62.0 m.sq	148.8 m.cu	28	13	-	-	-	-	41	19	12	-	-	-	-	31	14	-	6	-	-	6	1	7	8
2B Min	74.5 m.sq	178.8 m.cu	N/A	10	12	-	-	-	38	17	15	-	-	-	-	32	16	-	5	2	-	7	1	5	6
2B Mean	75.8 m.sq	181.8 m.cu	N/A	12.5	12	-	-	-	38.5	17	15.5	-	-	-	-	32.5	16	-	5	2	-	7	1	5	6
2B Max	77.0 m.sq	184.8 m.cu	N/A	15	12	-	-	-	39	17	16	-	-	-	-	33	16	-	5	2	-	7	1	5	6
2B Bglw	62.5 m.sq	150.0 m.cu	24	21	-	-	-	-	45	18	13	-	-	-	-	31	12	-	6	-	-	6	1	5	6
2B Wc Bw	72.0 m.sq	172.8 m.cu	22	19	-	-	-	-	41	19	14	-	-	-	-	33	14	-	6	-	-	6	1	5	6
3B Min	86.0 m.sq	206.4 m.cu	16	10	9	-	-	-	38	13	12	7	-	-	-	33	13	-	4	2	-	6	1	3	4
3B Mean	86.5 m.sq	207.6 m.cu	19	11	10	-	-	-	40.5	14	13	7.5	-	-	-	34.5	14	-	4.5	2	-	6.5	1	3.5	4.5
3B Max	87.0 m.sq	208.8 m.cu	22	12	11	-	-	-	43	15	14	8	-	-	-	36	15	-	5	2	-	7	1	4	5
4B Min	101.0 m.sq	242.4 m.cu	18	17	-	-	-	-	37	9	9	9	7	-	-	35	16	-	4	2	-	6	1	3	4
4B Mean	106.5 m.sq	255.6 m.cu	19	19	-	-	-	-	38	9.5	9	9.5	7	-	-	35	17	-	4	2	-	6	1	3	4
4B Max	112.0 m.sq	268.8 m.cu	20	21	-	-	-	-	39	10	9	10	7	-	-	35	18	-	4	2	-	6	1	3	4

Provider	Space provision ($m^2.p^{-1}$), by Number of Inhabitants									
	2	3	4	5	6	7	8	9	10	Mean
HBmin	19.75	16.45	13.93	14.02	12.35	14.47	18.90	20.14	19.74	16.64
HBmean	22.36	17.47	16.04	16.83	17.18	19.02	20.26	20.49	19.74	18.82
HBmax	25.43	18.8	23.81	21.14	22.83	23.65	22.07	20.68	19.74	22.02
HAmin	25.5	20.67	18.63	16.7	16.8	15.86	-	-	-	19.03
HAmean	25.5	21.8	19.0	17.6	16.8	16.0	-	-	-	19.5
HAmax	25.5	24.0	19.25	19.0	16.8	16.0	-	-	-	20.09

Table of mean net floor areas ($m^2.p^{-1}$) of typical dwellings of a national house builder (H B) and national housing association (H A)

The figures at the lower end of the occupancy scale, 2 inhabitants in particular, are higher than values further up the scale. This is due to the areas of common functions, such as the kitchen, being divided across fewer people. For example, a kitchen for five people is unlikely to be two and a half times the area of a kitchen for two people. This can be demonstrated by the percentage analysis of space use of the dwellings. The proportion of the area occupied by the kitchen drops from 15 percent in a two person dwelling to 10 percent in a five person dwelling. In terms of area this equates to a kitchen of $6.8m^2$ in the two person dwelling and $8.2m^2$ in the five person dwelling. Therefore, in the two person dwelling, this area will be divided by two in the area per occupant calculation, whereas it will be divided by five in the five person dwelling; this results in the higher value of area per occupant in the lower occupancy dwellings. In the national house builder figures, the area per occupant then dips in the four and five person dwellings, the typical three bedroom dwellings, and the rises again, as they move toward the larger, more 'luxurious' dwellings.

This can be viewed in comparison to the national housing association figures, where there is a continuous downward trend in the area per inhabitant as the number of occupants rises. This is due to the continued influence of increasing numbers over the common areas, described above, and that the larger dwellings do not become more 'luxurious,' as the house builder dwelling do.

The traditional yardstick for minimum space standards is, as it is known colloquially, the 'Parker Morris' standard. Published in 1961 the Parker Morris report, entitled *Homes for*

Today and Tomorrow,[2] was primarily concerned with space standards and heating. In its conclusion, the report advocated that space standards should be determined by the number of inhabitants within a particular house type, as oppose to minimum room standards, which had been the previous criterion. The Parker Morris standards became mandatory for public sector housing in 1967; they were never formally adopted or applied to the private sector. In 1981, the Government revoked the compulsory space standards that were based on the recommendations of the Parker Morris report, and housing associations were therefore permitted to build to any standard of internal areas the perceived to be consistent with the Housing Corporation's Design Guidance. Parker Morris is still generally recognised as of value, and remains the traditional yardstick by which to judge space standards.

The Parker Morris standards, which are also based on the net floor area per inhabitant, can be viewed against the current typical products of a national house builder and national housing association in the following table.

Provider	Mean Net Floor Area ($m^2.p^{-1}$), by Number of Inhabitants									
	1	2	3	4	5	6	7	8	9	10
HB	-	22.36	17.47	16.04	16.83	17.18	19.02	20.26	20.49	19.74
HA	-	25.5	21.8	19.0	17.6	16.8	16.0	-	-	-
PM	32.0	19.9	23.81	18.5	17.4	15.78	-	-	-	-

Table of mean net floor areas ($m^2.p^{-1}$) of typical dwellings of a national house builder (H B) and national housing association (H A) and the Parker Morris (P M) standards.

The overall mean values of the mean net floor area of a dwelling per occupant for the three categories of national house builder, national housing association and the Parker Morris standard for all of the house types are summarised below:

Provider	Mean floor area per inhabitant ($m^2.p^{-1}$)
National house builder	18.82
National housing association	19.45
Parker Morris	21.21

Overall mean floor area per inhabitant.

[2] Department of the Environment. *Homes for Today and Tomorrow,* London: HMSO, 1961.

Designing with higher standards has been demonstrated as achievable. In two low-energy dwellings in Sheffield, taking account of energy consumption, water conservation and the environmental impact of materials, the internal room sizes were 13 percent above the Parker Morris space standards. Furthermore, the dwellings construction costs were £6,500 below the Housing Corporation budget for conventional housing.[3]

In a study by the Building Research Establishment, dwellers were questioned about their subjective responses to the space within their dwellings, all of which were owner occupied, ranging in size from studio to four-bedroom, and all were built between 1981 and 1988.[4] 38 percent of the respondents rated the size of their dwelling as small, and only 32 percent stated that they had sufficient space all of the time. In response to being questioned on the reasons for why they did not have sufficient space, the following indicates the most popular responses:

Criticism of Space Provision	Responses (%)
Insufficient storage	31.1
Principal room too small	27.2
Kitchen too small	21.9
Insufficient space for guests	21.3
Bedrooms too small	20.6
Need another room	16.9
Bathroom too small	8.8

Criticisms of space provision in dwellings, by response[5]

These responses, in conjunction with the percentage analysis of the space use by function within the typical dwellings of a national house builder, will indicate where in terms of function an increase in the space standards of the dwelling would be most appropriate.

It is from research such as the analysis of the typical products of a national house builder and national housing association in the United Kingdom that the base figure of area per occupant is defined. From those, the benchmark values, as a factor increase of those base figures, can be derived. Determining this factor increase can be informed by European

[3] BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, London: HMSO, February 1996; and Smith, Maf, John Whitelegg and Nick Williams. *Greening the Built Environment*, London: Earthscan, 1998.
[4] Oseland, N. A. 'Improving Space in Homes, Building Research Information Paper *IP 9/92*, Building Research Establishment, May 1992.

comparatives, which demonstrate how new dwellings in the United Kingdom compare with European standards. The Drawn Studies, such as Drawn Study 4 of the dwellings for Allerton Bywater, will demonstrate what could be achieved by national house builders in the United Kingdom, as a benchmark of innovative construction.

Drawn Study 2, at the dwelling scale of the Glasgow project, can contribute to the benchmark of space standards. It is of particular relevance in being a project for flats, as due to data available the existing analysis, whilst including flats, has a preponderance toward the scale of individual dwellings, and flats are a significant dwelling type in urban situations. The analysis in terms of area can be summarised as follows; the reference a and b refers to the different dwelling configurations, and therefore sizes, that are present in the study.

Area	Number of Inhabitants					
	2a	2b	3	4a	4b	Mean
Dwelling area (m^2)	36	72	72	109	140	85.8
Area per inhabitant ($m^2.p^{-1}$)	18.0	36.0	24.0	27.3	35.0	28.1

Area per Inhabitant ($m^2.p^{-1}$) for Drawn Study 2

A similar process can be undertaken for the dwellings of the drawn studies for the Allerton Bywater Millennium Community Competition, from Drawn Study 4. The following table presents the areas for each of the dwelling types, and the corresponding area per occupant, of one internal configuration. These are the maximum designed occupancy levels, and therefore any other variation would lead to a higher space standard.

Area	Number of Inhabitants						
	4a	4b	5a	5b	7a	7b	Mean
Dwelling area (m^2)	78	73	96	100	127	125	99.8
Area per inhabitant ($m^2.p^{-1}$)	19.5	18.3	19.2	20.0	21.2	20.8	19.8

Area per Inhabitant ($m^2.p^{-1}$) for Drawn Study 4

Of particular note is the very small variation in area per inhabitant between the different

[5] Ibid.

dwelling types. Whereas the area per inhabitant dipped at the four and five person dwellings for the national house builder, and showed a continual downward trend for the national housing association, with a variation of up to almost 2.8 m^2 from the mean, the dwellings in Drawn Study 4 only vary by a maximum of 1.5 m^2 from the mean. This can be attributed to the internal arrangement of the dwelling types, where shared spaces, such as the kitchen, increased in area in accordance with the increase in the overall dwelling area and occupancy level. This is a logical arrangement, for as the kitchen, as an example, is increasingly becoming an informal gathering space for the family, then it should increase in response to increasing numbers of inhabitants.

It is also worthwhile to note that in the subsequent development of the project, following its success in the competition, the house builders involved reacted against the space standards proposed, and sought to reduce them to levels that are below the areas of the dwellings of the national house builder.[6] The values proposed by the national house builder for the sizes of the dwellings were 57.6 to 65.0 m^2 for a 2 bedroom dwelling, 78.9 to 83.6 m^2 for a 3 bedroom dwelling and 111.5 m^2 for a 4 bedroom dwelling. In terms of area per inhabitant, assuming the same number of inhabitants as the original dwellings proposed in Drawn Study 4, these figures can be translated as 15.5 m^2.p^{-1} for the 2 bedroom dwelling, 16.3 m^2.p^{-1} for the 3 bedroom dwelling and 15.9 m^2.p^{-1} for the 4 bedroom dwelling, based upon mean the area.

The table overleaf presents comparable figures of average floor area per occupant for seven European countries. However, no methodology accompanies these figures to explain how they have been measured and calculated, such as if they are net floor areas, and therefore if there is any potential direct comparability of these figures to the primary analysis of the net floor areas per occupant current products of the national house builder and housing association summarised above.

[6] Minute of meeting between Gleeson Homes, Gleeson City Living and Aire Design, at Redrow Homes Office, 6 July 1999.

Country	Area per Inhabitant ($m^2.p^{-1}$)
Denmark	51
Sweden	44
Holland	38
Germany	36
France	33
UK	32
Italy	32

Average floor area per Inhabitant by country in 1991[7]

The figure for the United Kingdom of 32 m^2 per inhabitant is far above that of the above figures; therefore it would be imprudent to directly compare the values of other countries with the figures determined above. However, it would be reasonable to presume that the figures for each country within this table have been measured and calculated on the same basis for each, and therefore the graph can be interpreted so that each of the other six countries is represented as a percentage of the average floor area per occupant for the United Kingdom. This information can then be used to translate the mean figures of a United Kingdom national house builder (18.8 m^2) and housing association (19.5 m^2) into comparable figures for the other European countries. This can be represented in the following table:

Country	Percent Variation	Effect on UK Builder	Effect on UK Association
Denmark	159	29.9	31.0
Sweden	138	26.0	26.9
Holland	119	22.4	23.2
Germany	113	21.3	22.0
France	103	19.4	20.1
Italy	100	18.8	19.5

Average floor area per Inhabitant for six European countries represented as a percentage of the United Kingdom's average floor area per inhabitant, and then interpreted into a figure of area per inhabitant

A composite table can also be created that will present the typical products of the house building industry in the United Kingdom against traditional space standards, the drawn

[7] Figures were provided in personal communication from The Danish Ministry of Housing

studies, and European equivalent standards that have been extrapolated to give comparable areas to the dwellings of the national house builder and housing association.

Provider	Mean Net Floor Area ($m^2.p^{-1}$), by Number of Inhabitants									
	1	2	3	4	5	6	7	8	9	10
HB	-	22.4	17.5	16.0	16.8	17.2	19.0	20.3	20.5	19.7
HA	-	25.5	21.8	19.0	17.6	16.8	16.0	-	-	-
PM	32.0	23.7	19.9	18.5	17.4	15.8	-	-	-	-
DS Two	-	27	24	31.2	-	-	-	-	-	-
DS Four	-	-	-	18.9	19.6	-	21.0	-	-	-
Dk	-	35.6	27.9	25.4	26.7	27.3	30.2	32.3	32.6	31.3
Sw	-	30.9	24.2	22.1	23.2	23.7	26.2	28.0	28.3	27.2
NI	-	26.7	20.8	19.0	20.0	20.5	22.6	24.2	24.4	23.4
Gm	-	25.3	19.8	18.1	19.0	19.4	21.5	22.9	23.2	22.3
Fr	-	23.1	18.0	16.5	17.3	17.7	19.6	20.9	21.1	20.3

Table of mean space standards ($m^2.p^{-1}$) of typical dwellings of UK house building industry, Drawn Studies Two and Four, and European equivalent standards of house building.

In terms of the quality of the internal environment it can be presumed that the ideal dwelling will have space standards that are as high as possible, within the terms of cost and quality constraints. However, if they are too great they will have an adverse effect on the value of density; the proposed benchmark values will therefore have to maintain the quantitative value of density, in terms of people per hectare with high internal space standards. The dwelling of long dimensions within the city of short distances may, in those terms, be something of a compromise, if not an oxymoron. Furthermore, the additional materials required to construct the dwelling, and the additional energy required to heat and illuminate it will also be affected detrimentally if the space standards are increased. This can be evaluated by the assessment methodology of those benchmarks, which are measured in units with a dimension that accounts for floor area, $kWh.m^{-2}$ and $kWh.m^{-2}.a^{-1}$ respectively.

The analysis of the European best practice dwelling was also applied to the analysis of actual projects, as the values above are based upon applying a general percentage variation between the space standards of different countries to the of the national house builder. This also enabled the research to focus upon urban dwellings, which may be smaller in area. The specific projects that were studied are summarised in the table overleaf.

European Comparative	Number of inhabitants	Area per Inhabitant ($m^2.p^{-1}$)
Student Housing, Graz	1	28
Laivapokia, Helsinki	2	25
Diana Have, Copenhagen	3	21
SP15 D/52, Amsterdam	4	19
Sijzenbaan, Deventer	5	19.8
Jungerhalde	6	21

Specific European best practice comparatives

Research conducted into space standards of housing association dwellings[8] undertook, as a part of its remit, a study of space standards of new-build houses and flats as affected by design method and contract type. These values can be translated into values of floor area per occupant, as affected by design method and contract type, and is represented in the table/graph below. This may have an influence in the Procurement criterion of the protocol.

Number of occupants	Mean floor area per Inhabitant ($m^2.p^{-1}$)					
	Contract type			Design method		
	Tender	Off the shelf	D and B	Bespoke	Cont'or des'd	HA Std des
1 (flat)	27.7	**47.9**	33.2	-	-	-
1 (house)	39.0	-	-	39.0	-	-
2 (flat)	**23.3**	22.2	22.5	-	-	-
2 (house)	25.1	**26.5**	23.7	24.7	-	-
3 (flat)	**20.0**	19.3	19.4	-	-	-
3 (house)	20.4	19.4	23.2	19.8	**22.1**	19.2
4 (flat)	**18.3**	-	15.8	-	-	-
4 (house)	17.5	**22.2**	17.6	18.0	**19.1**	17.9
5 (flat)	**21.0**	-	17.9	-	-	-
5 (house)	16.4	16.4	16.7	16.7	**16.7**	16.4
6 (house)	15.1	**21.3**	16.0	15.2	**18.2**	15.4
7 (house)	15.0	-	16.3	14.3	15.9	16.0
8 (house)	-	15.6	16.1	**16.6**	15.6	14.3
9 (house)	13.3	-	-	13.3	-	-
Mean	20.9	**23.4**	19.9	**19.7**	17.9	16.5

Mean floor area per occupant ($m^2.p^{-1}$) of housing association dwellings by contract type and design method. (Bold indicates highest values for each type/method for each dwelling type)

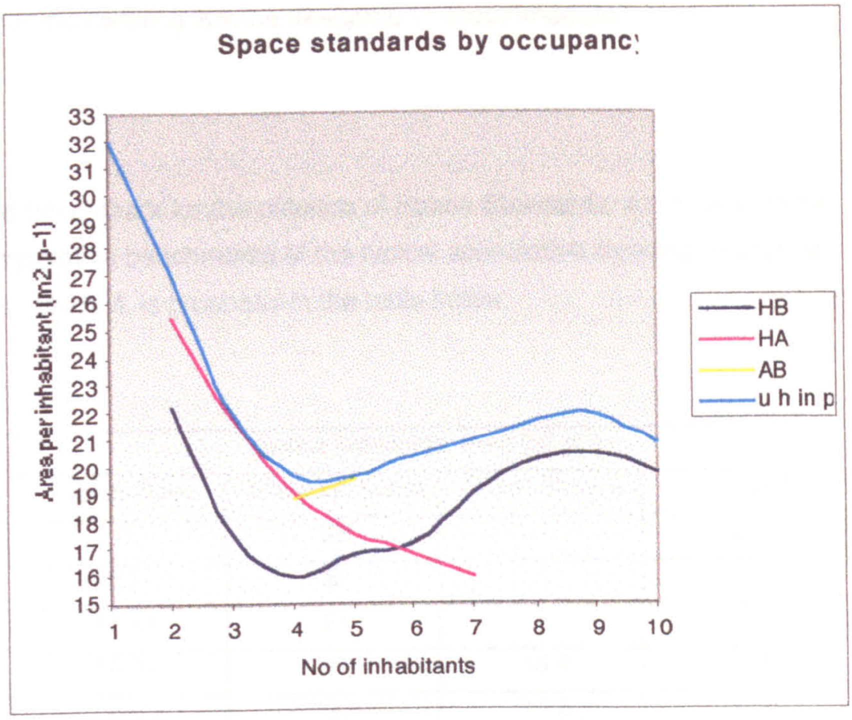
For contract type, Whilst Off the Shelf (OTS) dwellings, properties purchased which are already completed, but are unsold, by a private builder or developer, appear to be well distributed in terms of highest area per occupant, Tender and Design and Build Package (D and BP) display an evident clustering. For Tender this is for all of the flats, with the exception of the one person flat which is markedly lower. For D and BP, the clustering is toward the larger dwellings of five to eight occupants. However, in terms of the mean values, it is the OTS dwellings that have the highest overall mean value; although if the anomalous value of the one person flat is disregarded from the calculation of the mean, the value would be 20.4 m^2, the highest mean value would then be Tender.

In terms of design method, the contractor's standard design of house type provides a higher number of largest areas for a given occupancy figure. However the Bespoke design method has the highest overall mean value; this could be due to the Bespoke being the only design method with values below an occupancy level of three. The area per occupant of dwellings with smaller numbers of occupants, those of one and two, tends to be higher, as the primary analysis of the national house builder and housing association dwellings demonstrates, refer to table above. Therefore, if these figures are discounted, and the means are calculated from the mean area per occupants for numbers of occupants represented more equally by each design type, then the mean values of area per occupant are: Bespoke, 16.3 $m^2.p^{-1}$, Contractor's standard design, 17.9 $m^2.p^{-1}$, and Housing association standard, 16.5 $m^2.p^{-1}$. Therefore, the contractor's standard design has the highest mean area per inhabitant also.

It is now possible to plot a graph that will represent the relationships between the different space standards of the national house builder, national housing association and Drawn Study Number Four. In the case of the latter, a specific attempt was made at the design stage to increase the space standards above those of the typical product of the national house builder. Onto this graph can then be overlaid the line representing standards of the 'urban house in paradise'. This line has been derived by using the line of the national house builder to determine how the area per occupant changes for increasing numbers of occupants, but removing the excessive dip between three and five occupants, and applying this to the standards of Drawn Study 4. This will create a set of space standard values, in area per occupant, that will vary for the number of occupants, and will provide greater space than is currently being provided by the housing construction industry.

---

[8] Walentowicz, Paul. *Housing Standards after the Act - A Survey of Space and Design Standards on Housing Association Projects in 1989/90*, London: National Federation of Housing Associations, 1992.
[9] This is derived from the definition of net floor area used in the Parker Morris report.



Graph of Space Standards by occupancy

The analysis from which these values are determined is based largely on two storey dwellings. Drawn Study 7 showed that the space standard for a six person dwelling, of 122.4 m^2 was difficult to achieve in a three storey dwelling, due to the space required for additional circulation; its floor area was measured at 124.08 m^2. This is also borne out in the analysis of the space standards of the national house builder. Therefore, a proviso is added to this benchmark that for dwelling of over two storeys, 4 m^2 per floor should be added to the total area given by the Space Standards: Area benchmark to allow for additional circulation.

Methodology of Assessment

The value of area per occupant for a dwelling will be determined by dividing the net floor area of the dwelling by the maximum number of occupants that the dwelling was designed to accommodate. Basing the assessment on the designed occupancy level retains consistency with the Density: Quantitative benchmark. The net floor area is that which is enclosed within the external walls; it includes the area occupied by any internal partitions, and the area occupied by any staircase on each floor. It excludes the area occupied by an external balcony.[9] Conversely, the net floor area of the 'urban house in paradise' can be determined by multiplying the value of the area per occupant in the table below by the number of occupants that the dwelling is to be designed to accommodate.

Conclusion

Therefore, the proposed benchmark for the criterion of Space Standards: Area, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparatives and Drawn Study 4, is proposed in the table below.

Number of inhabitants	Space Standards: Area ($m^2.p^{-1}$)			
	Typical Spec	European Comp	Drawn Study 4	U H in P
1	-	28	-	32
2	22.36	25	-	27
3	17.47	21	-	22
4	16.04	19	18.9	19.7
5	16.83	19.8	19.6	19.7
6	17.18	20.5	-	20.4
7	19.02		20.3	21.0
8	20.26		-	21.7
9	20.49		-	21.9
10	19.74		-	20.9

Space Standards: Area benchmark for the 'urban house in paradise'

3.31 Space Standards: Volume

In traditional space standards, such as Parker Morris, area has always been the criterion of assessment. However, in the perception of space, the volume of that space is more crucial than only the area. These two criteria are, of course, interrelated; this was demonstrated in the dwellings of Allerton Bywater, Drawn Study Four. Through maximising the efficiency of the ratio between usable volume and the volume enclosed by the external skin of the dwelling, for example utilising the volume within the roof pitch, an increase in area of ten percent was translated into and increase in volume of thirty-five percent. However volume is not solely a product of area, and is dependent on the three-dimensional configuration of the dwelling as opposed to area, which is only two-dimensional. Therefore in the pursuit of a spatially desirable dwelling, in addition to benefits to daylight penetration and air circulation, the volume per inhabitant of the dwelling will be benchmarked as well as area per inhabitant.

To determine a base level, the same process can be followed for determining the volume per occupant of the typical products of a national house builder and housing association, as was conducted for the analysis of area. This is represented in the following table.

Provider	Space provision ($m^3.p^{-1}$), by Number of Inhabitants									
	2	3	4	5	6	7	8	9	10	Mean
HBmin	47.40	39.49	33.42	33.65	29.64	34.73	45.36	48.34	47.38	39.93
HBmean	53.65	41.92	38.50	40.38	41.22	45.64	48.63	49.17	47.38	45.17
HBmax	61.02	45.12	57.15	50.74	54.80	56.76	52.96	49.62	47.38	52.84
HAmin	61.02	49.60	44.70	40.08	40.40	38.06	-	-	-	45.67
HAmean	61.02	52.40	45.48	42.19	40.40	38.23	-	-	-	46.65
HAmax	61.02	57.60	46.20	45.60	40.40	38.40	-	-	-	48.23

Table of mean net volume ($m^2.p^{-1}$) of typical dwellings of a national house builder (H B) and national housing association (H A)

From analysis of the typical products of a national house builder and national housing association in the United Kingdom the base figure of area per occupant is defined. From those, the benchmark values, as a factor increase of those base figures, can be derived. As for the Space Standards: Area benchmark, determining this increase can be informed by European comparatives, which demonstrate how new dwellings in the United Kingdom compare with European standards. The Drawn Studies, such as Drawn Study 4 of the dwellings for Allerton Bywater, will demonstrate what could be achieved by national house builders in the United Kingdom, as a benchmark of innovative construction.

The second Drawn Study of the individual dwellings in the Glasgow project, just as it contributed to the space standards benchmark of area, can be used in inform the space standards benchmark in terms of volume. The volume per dwelling, and corresponding volume per occupant can be summarised in the following table:

Volume	Number of Inhabitants					
	2a	2b	230.4	4a	4b	Mean
Dwelling volume (m^3)	115.2	230.4	72	348.8	448.0	274.6
Volume per inhabitant ($m^{£}.p^{-1}$)	57.6	115.2	76.8	87.2	112.0	89.8

Volume per Inhabitant ($m^3.p^{-1}$) for Drawn Study 2

In a similar manner, the space standards of Drawn Study 4, of the individual dwelling at Allerton Bywater, can be presented as volume per inhabitant for each of the dwelling types. As described above, it was a specific intention to increase the internal volume of the dwelling above that typical of a national house builder; this was achieved both through increasing the area of the dwelling, ceiling heights and increasing the proportion of inhabitable space within the envelope of the dwelling. Once again, as for the area per inhabitant, this is for the maximum occupancy configuration, and the value of the space standards will be higher for other configurations.

Volume	Number of Inhabitants						
	4a	4b	5a	5b	7a	7b	Mean
Dwelling volume (m^3)	220	222	276	300	360	370	291
Volume per inhabitant ($m^{£}.p^{-1}$)	55.0	55.5	55.2	60.0	60.0	61.7	57.9

Area per Inhabitant ($m^2.p^{-1}$) for Drawn Study 4

The analysis of the European best practice dwelling can also applied to the volume of the dwelling. This is focussed upon the specific urban projects that were analysed above. These are summarised in the table overleaf.

European Comparative	Number of inhabitants	Volume per occupant ($m^2.p^{-1}$)
Student Housing, Graz	1	75.6
Laivapokia, Helsinki	2	67.5
Diana Have, Copenhagen	3	63
SP15 D/52, Amsterdam	4	53.2
Sijzenbaan, Deventer	5	49.5
Jungerhalde	6	55.7

Specific European best practice comparatives

The dwellings in Drawn Study 4 were designed with mean ceiling heights of three metres, to achieve the desired increase in volume over and above that of area. Therefore, the benchmark of Space Standards: Volume for the 'urban house in paradise' is established both through multiplying the area benchmark by a height of three, and informing this value with the comparative analysis above.

Methodology of Assessment

The value of volume per inhabitant for a dwelling will be determined by dividing the net volume of the dwelling by the maximum number of occupants that the dwelling was designed to accommodate. The net internal volume is the space enclosed by the external envelope of the dwelling and any party walls; it will include any internal floors within a dwelling, but exclude separating floors between dwellings. Therefore it is comparable to the assessment of floor area. Conversely, the target internal volume of the 'urban house in paradise' can be established by multiplying the value of the benchmark of volume per inhabitant in the table below by the number of inhabitants that the dwelling is to be designed to accommodate.

Conclusion

Therefore, the proposed benchmark for the criterion of Space Standards: Volume, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparatives and Drawn Study 4, is proposed in the table overleaf.

Number of inhabitants	Space Standards: Volume ($m^3.p^{-1}$)			
	Typical Spec	European Comp	Drawn Study 4	U H in P
1	-	75.6	-	96
2	52.6	67.5	-	81
3	41.1	63	-	66
4	37.6	53.2	55.3	59.1
5	39.5	49.5	57.6	59.1
6	40.4	55.7	-	61.2
7	44.7	-	60.9	63.0
8	47.7	-	-	65.1
9	48.2	-	-	65.7
10	46.3	-	-	62.7

Space Standards: Volume benchmark for the 'urban house in paradise'

3.32 Thermal Performance

The thermal performance of the fabric of a dwelling is of critical importance to its performance; as the external envelope is one of the most durable parts of the dwelling, it will significantly influence the energy consumption of the dwelling throughout its life span. It will be inextricably linked to the benchmark of its energy consumption, and in particular the space heating component of that value. Therefore, the value of the benchmarks of thermal performance will take their lead from that criterion, of 25 $kWh.m^{-2}.a^{-1}$, and in particular for the total energy consumption, and <10 $kWh.m^{-2}.a^{-1}$ for space heating.

There are two methods of determining the thermal performance of a dwelling under the Building Regulations, elemental and target. The elemental analysis considers the performance of each of the elements that the envelope of the dwelling is composed of, such as walls, floors and roof. The target value considers the overall performance of these elements, accounting for their area as a proportion of the total area of the envelope. In the literature review of low energy dwellings, without exception the thermal performance has been quoted as the elemental values. For the purposes of comparability, it is the target values that will be benchmarked for the 'urban house in paradise'. Furthermore, the elemental values are more transparent, demonstrating the performance of every element, rather than proposing them as an amalgamation.

The standard United Kingdom Building Regulation requirements can be taken as the basis from which to establish a benchmark of thermal performance for the 'house in paradise.' These are summarised as the Elemental U-values for a SAP of over 60:[1]

[1] The U-values required by the Building Regulations are higher for a dwelling with a SAP rating below 60. However, it is felt that as, due to its performance, the 'urban house in paradise' is likely to have a SAP rating above 60, the Building Regulation U-values also for a dwelling with a SAP rating over 60 would be a more relevant comparison.

Element	U-value (W.m^{-2}.K^{-1})
Roofs	0.25
Flat roofs or the sloping parts of a room-in-the-roof	0.35
Exposed floors and ground floors	0.45
Exposed walls	0.45
Semi-exposed walls and floors	0.6
Windows, doors and roof lights	3.3

Standard Building Regulation U-values for England and Wales[2]

The benchmarks for energy consumption were determined with reference to a number of sources, including to best practice in ultra-low-energy dwellings, as published in the BRECSU's *General Information Reports Number 38* and *39*.[3] Dwellings from these with comparable performance are summarised below, with their corresponding U-values. These demonstrate U-values for dwellings with energy requirements, in terms of overall energy consumption and space heating, within the region of that proposed for the 'house in paradise'.

Project	En'gy (kWh.m^{-2}.a^{-1})		U-value (W.m^{-2}.K^{-1})					
	Space	Total	Roof	Wall	Win	Floor	B/Wall	B/Floor
The Berm House	0	-	0.14	0.16	2.6	0.65	-	-
Duncan House	1	-	0.09	0.12	2.1	0.15	-	-
Zero-Energy	-	14	0.13	0.15	1.2	-	0.19	0.19
Southwell house	4	22	0.07	0.14	1.15	0.6	0.3	-
Elmsett Eco House	-	25	0.08	0.1	0.8	0.13	-	-
Kings X Eco House	-	25	0.11	0.12	0.8	0.14	-	-
Zero-Energy House	9	-	0.11	0.12	1.9	0.13	-	-
Passiv Haus	10	32	0.09	0.14	0.7	0.16	-	-
Low-Energy Urban	10	-	0.15	0.17	0.7	0.15	-	-
House B	-	42	0.09	0.14	2.1	0.1	-	-
Waterloo Region	-	51	0.13	0.15	1.0	-	-	-
Den'k IEA Task 13	15	<60	0.11	0.11	0.8	-	-	-
Lower Watts House	-	65	0.12	0.22	1.7	0.22	-	-

Comparative U-values for Ultra-Low-Energy Dwellings[4]

[2]Department of the Environment and the Welsh Office. *The Building Regulations – Approved Document L: Conservation of Fuel and Power*, London: HMSO, 1995.
[3] BRECSU, *General Information Report 38* and *39*, London: HMSO, 1996

In 1998 a report was published that had been prepared for the Joseph Rowntree Foundation, by Robert Lowe and Malcolm Bell of Leeds Metropolitan University's Centre for the Built Environment, with the intention of,

> ... instigating debate over future developments in energy efficiency aspects of the Building Regulations in the UK.[5]

A critical review was made of the current Regulations, with particular reference to space heating and thermal performance of the dwelling's fabric. In short, the objective is set to reduce average U-values by 40 percent by the year 2000, and by 60 percent by the year 2005.

> The latter level, modeled on the current Swedish Building Regulations, will reduce the space heating requirements of a typical semi-detached house in the north of England by almost 90 percent compared with the same dwelling built to current UK Building Regulations.[6]

Following objections that the elemental thermal performance standards for roof, wall, floor and glazing restricted the freedom of the designer, and makes no constraint on the efficiency of the heating system, the Energy Target system was introduced for dwellings in the 1990 edition of the Building Regulations. This was based on the BREDEM model, refer to the Energy Consumption: Inhabitation criterion, Annexe 3.16. In 1995 this was revised into the Energy Rating Method, based on a specified value of the energy efficiency as determined by the Government's Standard Assessment Procedure.

Lowe and Bell undertook a comparison of two scenarios, of low and high versions of a typical dwelling, and analysed both by Elemental and Target U-value methods of assessment. The reduction in energy consumption of the high efficiency over the low efficiency scenario by the Elemental method was 34 percent; whereas under the Target U-value method the reduction was 25 percent. The difference occurs because of the trade-off allowed for under the Target U-value method. Therefore, for the reduction of overall energy consumption, it is evidently desirable to have elemental U-values to determine the performance of the skin, rather than a target value based on the Building Regulations model, but also an overall energy consumption value, as thermal performance is but one of a number of criteria that will effect the level of overall energy consumption.

In BRECSU's *General Information Report Number 53*, U-values are proposed for both a zero

---

[5] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998, p. 1.
[6] Ibid., p. 2.

CO_2 emission and zero heating dwelling, against the current Building Regulation standards.[7] These are presented in the following table.

Element	U-Value ($W.m^{-2}.K^{-1}$)		
	1995 Building Regs	Zero CO_2	Zero Heating
Roof	0.25	0.10	0.08
Flat roof	0.35	0.10	0.08
Ground floors	0.45	0.20	0.10
Exposed floors	0.45	0.20	0.10
Exposed walls	0.45	0.20	0.14
Semi-exposed walls	0.6	0.20	0.14
Window, door, r'light	3.3	2.20	1.70

Table of U-values for 1995 Building Regulations, Zero CO_2 and Zero Heating Dwelling[8]

The Building Research Establishment's environmental assessment of dwellings, *EcoHomes*, awards credit for improving the thermal performance of the dwelling's envelope, in comparison with the mandatory requirements of the Building Regulations. Maximum credit is awarded for a 30 percent improvement.[9] In terms of current standards, this would equate to the following U-values: roofs 0.18 $W.m^{-2}.K^{-1}$, exposed floors and ground floors 0.32 $W.m^{-2}.K^{-1}$, exposed walls 0.32 $W.m^{-2}.K^{-1}$, semi-exposed walls and floors 0.42 $W.m^{-2}.K^{-1}$, and windows, doors and roof lights 2.3 $W.m^{-2}.K^{-1}$.

In June 2000 a consultation paper was published on proposals for revising the Part L of the Building Regulations relating to energy efficiency requirements; these included the thermal performance of dwellings.[10] In terms of elemental values, the proposals are for a sequential improvement in the standard, with effect from the initial date when the Approved Document comes into effect, and a further improvement 18 months later. The performance demanded is also dependent upon the type of heating system to be specified.

---

[7] BRECSU. 'Building a Sustainable Future - Homes for an Autonomous Community,' *General Information Report Number 53*, London: HMSO, October 1998.
[8] Ibid.
[9] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.
[10] Department of the Environment, Transport and the Regions. *The Building Act 1994 – Building Regulations - Proposals for Amending the Energy Efficiency Provisions – A Consultation Paper Issued by Building Regulations Division*, London: HMSO, June 2000.

	Type of Heating System			
	Gas or oil central heating with boiler SEDBUK not less than the value in the table below		Other gas or oil system, any electrical or solid fuel system, or undecided	
Pitched roof, insulation between rafters	0.25	0.20	0.22	0.18
Pitched roof, insulation between joists	0.20	0.16	0.18	0.16
Flat roof	0.25	0.25	0.22	0.22
Wall	0.35	0.30	0.31	0.27
Floor	0.30	0.25	0.27	0.22
Average of windows, doors and roof lights	2.20	2.00	2.00	1.80

Proposed U-values in consultation document on revisions to Part L of Building Regulations

	Minimum boiler SEDBUK (percent)	
Central Heating Fuel	Initial	Post 18 months
Mains natural gas	75	78
LPG	82	85
Oil	85	88

Minimum boiler SEDBUK rating for determining U-values

The consultation document goes on to propose subsequent amendments to these standards in a further five years; these are:

Element	U-value ($W.m^{-2}.K^{-1}$)
Roofs: insulated between or over joists	0.16
Roofs: integral insulation in structure	0.16
External walls	0.25
Ground floor	0.22
Average of all windows, doors and roof lights	0.6

Proposed amendments to revised regulations after five years

To be progressive, the proposed thermal performance benchmarks for the 'urban house in paradise' will clearly have to innovate upon these standards.

As far back as 1983, Sweden adopted thermal insulation standards that made 50 to 60 $kWh.m^{-2}.a^{-1}$ the permissible maximum heat loss for dwellings,[11] which can be compared with the current typical space heating requirement of a dwelling in the united Kingdom of 89 $kWh.m^{-2}.a^{-1}$. In a comparison between the current Building Regulation requirement of thermal performance for the United Kingdom and Denmark and Sweden[12] reveals radically different standards. These are summarised in the following table:

Element	U-Value ($W.m^{-2}.K^{-1}$)		
	UK	Denmark	Sweden
Roof	0.25	0.15	0.15
Exposed walls	0.45	0.3	0.25
Semi-exposed walls and floors	0.45	-	-
Floors	0.45	0.3	0.2
Windows, glazed doors and roof lights	3.3	2.0	1.3
Opaque doors and hatches	-	1.0	0.6

Comparison of United Kingdom, Danish and Swedish thermal performance regulations[13]

In terms of a wider perspective, these values can also be compared with two scenarios proposed by the Canadian Residential Energy Efficiency Database, for minimum recommended standards and those for an energy efficient dwelling. These are summarised in the table overleaf.

Element	U-Value ($W.m^{-2}.K^{-1}$)	
	Min Recommended	Energy Efficient

[11] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998, p. 13.
[12] Swedish Board of Housing, Building and Planning. *Building Regulations BBR 94 - BFS 1993:57, with Amendments BFS 1995:17, BFS 1995:65*, Boverket, 1995.
[13] Lowe and Bell, Op. Cit.

Roof	0.14	0.09
Walls above ground	0.29	0.14
Exposed cantilever	0.20	0.14
Floors over unheated spaces	0.29	0.14
Basement walls	0.48	0.29
Basement floors	0.56	0.56

Comparison of Minimum Recommended and Energy Efficient U-values[14]

Lowe and Bell conducted a comparative analysis of the United Kingdom, Danish and Swedish standards, in terms of consequent space heating requirements. The three standards were applied to the scenario of a typical dwelling located in the north of England; a 50 percent reduction was produced with the Danish standards, whilst an 88 percent reduction was produced by the Swedish standards. These differences are over and above what could be accounted for by climatic differences between the three countries; the climate of Denmark is not significantly different from that of some parts of the north of England. This will clearly assist when proposing benchmark levels for the energy consumption due to space heating for the 'house in paradise'. The value proposed should account for both the reduction in energy consumption as a result of the increased thermal performance, and also the increased efficiency of the heating system, and other contributory benefits, such as the contribution of solar warming; the value should be sufficient to ensure that it does not encourage the use of inefficient appliances by being achieved solely through the higher standards of thermal performance.

An additional consideration in terms of U-values, as identified by Lowe and Bell, is the distinction between the thermal performance of the element at the design stage, to which the Building Regulations apply, and the actual thermal performance of the element once built. The latter can be severely compromised through poor quality construction. This may be due to a lack of care or a lack of understanding of the technical issues involved.

In Sweden these potential discrepancies are accounted for through the application of correction factors to the U-values determined at the design stage. For typical levels of construction quality and supervision of site work the correction factor is 0.02 $W.m^{-2}.K^{-1}$, where supervision and control is significantly improved the factor is 0.01 $W.m^{-2}.K^{-1}$.[15] In the context of the level of the Swedish thermal performance standards, this factor is significant,

[14] Residential Energy Efficiency Database, 22 July 1999: www.its-canada.com/reed/index.htm
[15] Lowe, Robert and Malcolm Bell. Op. Cit.

for example it is over 13 percent of the U-value for roofs of 0.15 $W.m^{-2}.K^{-1}$.

The relationship between design element U-values and the actual performance once built, as affected by knowledge and quality, like air tightness which can be significantly affected by build quality, demonstrates the importance of the relationship between the designer and builder of the dwelling. This relationship can be significantly influenced by the procurement strategy adopted to deliver the dwelling. Therefore, the procurement strategy benchmark will be greatly affected by the importance of achieving the correct relationship between the relevant parties who design, construct and maintain the dwelling.

Danish Building Regulations the Elemental and Target value approaches are supplemented by a maximum value permissible for the energy consumption arising from heating and ventilation.

The comparative dwelling used to illustrate European best practice in the Energy Consumption: Inhabitation benchmark was the Passiv Haus in Darmstadt. This was also used as the comparative dwelling in the Quality of the Internal Environment: Air Tightness benchmark, as the energy consumption is so dependent upon the air tightness of the dwelling. For this reason the Passiv Haus is identified here a comparative dwelling.

Project	U-value ($W.m^{-2}.K^{-1}$)			
	Roof	Wall	Window	Floor
Passive Haus, Darmstadt	0.09	0.14	0.7	0.16

Performance of an example of European best practice in thermal performance

A more contemporary comparative can be given by the low energy dwellings for the Expo 2000 in Hanover. The performance of these innovative dwellings provides a more contemporary comparative of an urban dwelling project for 142 low-rise flats for 500 inhabitants.[16] This is summarised in the following table.

Project	U-value ($W.m^{-2}.K^{-1}$)	
	Wall	Window

[16] Bellew, Patrick and Jochen Kauschmann. 'Hanover Fare', *Building Services Journal*, August 2000.

Expo 2000, Hanover	0.137	1.3

Performance of an example of European best practice in thermal performance

In terms of glazing standards, the Swedish company Swedhouse UK, with manufacturing sources in the United Kingdom, produce a triple-glazed widow with low emissivity coatings with a U-value of 0.95 $W.m^{-2}.K^{-1}$.[17] A high performance window, with triple glazing, two low-emissivity coatings, an inert gas fill, such as argon, to the cavities, and a frame designed to minimise conduction losses, will have a whole window U-value of approximately 0.8 $W.m^{-2}.K^{-1}$.[18] Lowe reports of windows available in Canada with overall U-values between 0.73 and 0.90 $W.m^{-2}.K^{-1}$. In terms of doors, the Swedish Ekstrands Ekodoor, a composite panel insulated with a CFC-free foam, achieves a U-value of 0.55 $W.m^{-2}.K^{-1}$.[19]

In the fifth drawn study, Allerton Bywater - Technology of the Dwelling, the U-value performance was a significant improvement on United Kingdom standards. The values achieved were approximately 0.14 $W.m^{-2}.K^{-1}$ for the walls and roof elements.

Of course increasing the level of insulation will have an effect on the overall embodied energy of the dwelling, as measured by the Ecological Weight criterion. There will be an optimum level at which measures such as adding increasing depth to the insulation to the skin will cease to have an beneficial effect of reducing heat loss over the additional embodied energy and cost that is being added. Research has been conducted into optimal thermal insulation has revealed that, on the basis of environmental consequences, for a dwelling with a 100 year life span there is no immediate risk of installing too much insulation.[20]

---

[17] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.
[18] Residential Energy Efficiency Database. Op. Cit.
[19] Vale, Brenda and Robert Op. Cit.
[20] Lowe, R. J., J. S. Sturges and N. J. Hodgson. 'Energy Analysis and Optimal Insulation Thickness,' *Procedures of 2nd International Conference on Buildings and the Environment*, CSTB, 1997.
[21] Chartered Institution of Building Services Engineers. Op. Cit.; and Department of the Environment and the Welsh Office. *Approved Document L*, London: HMSO, 1995. Other sources to which reference has been made are: Anderson, B. R. 'U-values for Basements', *IP14/94*, Watford: Building Research Establishment, August 1994; Anderson, B. R. 'The U-value of Solid Ground Floors with Edge Insulation, *IP7/93*, Watford: Building Research Establishment, April 1993; and Anderson, B. R. 'The U-value of Ground Floors: Application to Building Regulations, *IP3/90*, Watford: Building Research Establishment, April 1990.

Methodology of Assessment

The U-value is dependent upon the surface resistances of the element, the thermal resistance of a cavity, if present, and the thickness and thermal conductivity of the materials that make up the element. It can be summarised in essence by the following equation:

$$U\ value = 1 / R_t$$

where R_t = sum of resistances

$$R_t = R_{so} + (thickness/\lambda) + (thickness/\lambda) + etc + R_{cav} + R_{si}$$

where R_{so} = external surface resistance
R_{si} = internal surface resistance
R_{cav} = resistance of the cavity
thickness = thickness of the material (m)
λ = thermal conductivity of material ($W.m^{-1}.K^{-1}$)

In general this equation can be used for all elements. However it will vary according to certain situations such as timber frame structures, where there is a thermal bridge of the insulation by the timber frame, and roof pitches, where the U-value is affected by the pitch of the roof. Two principal sources can been used to derive the methodology of the U-value calculations; these are Volume A of the *CIBSE Guide*, and *Part L* of the Building Regulations.[21]

The thermal performance of a timber frame wall can be derived from the following equation:[22]

$$R = 1 / (F_t / R_t) + (F_{ins} / R_{ins})$$

where F_t = fractional area of the stud = stud thickness / stud centres
F_{ins} = fractional area of insulation = $1 - F_t$
R_t = resistance of inner leaf through timber, derived by equation above
R_{ins} = resistance of inner leaf through insulation, derived by equation above

The resistance of the outer leaf can be calculated in the same way if it another layer of timber frame, or using the equation above if it is masonry. The total resistance of the wall can then be derived from the following equation:

$$U = 1 / (R_{inner} + R_{cav} + R_{outer})$$

[22] Department of the Environment and the Welsh Office. *Approved Document L*, London: HMSO, 1995

Two equations could be used to determine the ground floor U-value. The first is based on the perimeter and surface area of the floor, and is summarised in Appendix C of *Part L* of the Building Regulations. The other is more complex, and is dependent upon the length and breadth of the floor, the thickness of the surrounding wall and the thermal conductivity of the earth; this is summarised in Volume A of the *CIBSE Guide*, and as a revised version in the Building Research Establishment's Information Paper *IP 3/90*.[23] However, a disadvantage of the former is that it is based upon an assumed wall thickness of 300 mm. In a highly insulated dwelling the external walls could be significantly thicker than that; for example, in Drawn Study Four, the external walls are almost 700mm thick. This is likely to be relevant for the 'urban house in paradise', in which the benchmark targets for thermal insulation are proposed to be high. An advantage of the latter equation is that it accounts for variation in the wall thickness in determining the U-value. The significance of varying the wall thickness on the U-value of the ground floor can be demonstrated by equating the value twice, keeping all variables constant except for the wall thickness. The equation and values are:

$$U_{floor} = (2 \times \lambda_e / b \times \pi) \ln (2 \times b + w / w) \exp (b / 2 \times l)$$

where, λ_e = thermal conductivity of earth (1.4 $W.m^{-1}.K^{-1}$)
b = breadth of floor (6 m)
l = length of floor (10 m)
w = wall thickness (0.3 and 0.7 m)

This results in a U-value of 0.74 $W.m^{-2}.K^{-1}$ for a wall thickness of 300 mm, and 0.58 $W.m^{-2}.K^{-1}$ for a wall thickness of 700 mm; this is a difference of 21 percent. With such a significant variation, it would be imprudent not to account for wall thickness in the matrix; therefore the latter of the two equations was used. The *CIBSE Guide A* provides a method of accounting for insulation within the ground floor; this was also adapted into the matrix.

Where the dwelling has a pitched roof, the angle of this pitch will affect the U-value. This was accounted for within the matrix by adopting the formula proposed by the *CIBSE Guide* to calculate the U-value of roofs, which is:

$$\text{Sum of resistances } Rt = R_A \cos\theta + Rcav + R_B$$

where: R_A = Total resistances at angle to plane of ceiling
R_B = Total resistances in plane of ceiling (if applicable)
θ = Angle of roof ($\theta = 0$ if flat roof)

[23] Chartered Institution of Building Services Engineers. Op. Cit.; and Anderson. April 1990, Op. Cit. The latter also contains a graph that shows the correlation between the two methods, which

Conclusions

The typical standard of the dwelling built by a national house builder is taken as the current Building Regulations. The comparative standards of European best practice are based on a reflection of all the standards above, in terms of identifying an innovative standard for each element. The benchmark of the 'urban house in paradise' is based on an innovation upon these, but which is considered achievable.

Therefore, the proposed benchmark for the criterion of Thermal Performance, seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative and Drawn Study 4, is proposed in the table below:

Element	Thermal Performance ($kWh.m^{-2}.a^{-1}$)			
	Typical UK	Euro Comp	Drawn Study 5	U H in P
Roof	0.25	0.09	0.14	0.08
External walls	0.45	0.14	0.14	0.12
Ground, exposed floors	0.45	0.16	0.2	0.13
Windows, glazed doors and roof lights	3.3	0.7	2.9	0.8
Opaque outer doors	3.3	0.55	3.0	0.55

Thermal Performance benchmark of the 'urban house in paradise'

demonstrates that each is appropriate as the other in terms of accuracy.

3.33 Use of Recycled Materials

The lifecycle of recycled materials is a continuous loop, as opposed to the linear nature of the life span of non-recycled materials. One revolution of the loop, therefore, represents one cycle of use of the material, before it is recycled for another use. Thus we can think of the life span of the 'urban house in paradise' as one cycle; at the start of the cycle the maximum use must be made of recycled materials to prevent the depletion of the earth's resources, and then one must ensure the maximum potential to recycle the materials at the end of the revolution, to continue the circular pattern. The alternation of the linear life span of materials to a cyclic one was identified in chapter 3.0, refer to volume 1, as a ambition of the 'urban house in paradise.

If the ideal sustainable dwelling is described as one which is built only of renewable resources and consumes only renewable energy, then clearly there is a challenge to benchmark the criterion of recyclability as high as possible, in order to maximise the use of renewable resources.

The Second Law of Thermodynamics states that whenever a form of energy is converted from one state to another, there is inefficiency and waste.[1] Therefore, there will always be an embodied energy implication in recycling materials. However, one could argue that as this is, in effect, the extraction and processing of materials for the construction of a new building, the embodied energy element of recycling materials should be attributed to the next building in which they are to be used. There may need to be a qualitative benchmark to this criteria, as the process of recycling may consume more energy than the processing of raw material, but as recycled materials do not deplete natural resources, then it could well be the preferable option for the 'urban house in paradise'. However, research suggests that the energy embodied in recycled materials can be significantly less than that consumed in the processing of virgin ore; this is demonstrated in the table overleaf. However, as the recycling of materials still has an embodied energy implication, the direct reuse of materials is preferable.

[1] Nelkon, Michael and Philip Parker. *Advanced Level Physics*, Oxford: Heinemann Educational Books Limited, 1987.

Material	Energy Consumed in Processing. (BTU.lb^{-1})		
	Virgin ore	Recycled material	% saved by recycling
Steel	8,300	4,400	47
Aluminium	134,700	5,000	96
Copper	25,900	2,150	92
Glass	7,800	7,200	8
Plastics	49,500	1,350	97
Newspaper	11,400	8,800	23

Energy consumed by virgin and recycled processing for common materials[2]

There can be additional advantages to the use of recycled materials; an example of this was revealed during research and testing by the Building Research Establishment into the use of recycled aggregates in concrete beam and block flooring, a material quite commonly used in housing construction. The research showed that the block components can be manufactured using 75 percent recycled aggregates and still achieve adequate strength levels; however, in addition was an improvement in the level thermal conductivity over blocks with a lower percentage of recycled aggregate.[3]

It is important to make the distinction between recycling and 'down cycling.' In the latter, the material is converted into a use of lower significance than it originally had. This can be demonstrated by a Building Research Establishment case study of recycling waste from the demolition of an existing building on the site of their new 'office of the future'; in this example, the bricks of the original building had to be crushed to create hardcore, due to the strength of the mortar, as opposed to being reused as bricks.

In the recycling of deconstruction and demolition waste there may be a downgrading of the use of the material, for example concrete which is ground to make hardcore or aggregate, rather than being able to reuse that material for the same purpose, an example of which could be timber flooring. Therefore, the potential for using recycled materials within the 'urban house in paradise' will not, by default, be the same mass or volume as the quantity of materials that are recycled when a building is demolished.

---

[2] Hayes, D. Repairs, Reuse, 'Recycling – First Steps Toward A Sustainable Society', *Worldwatch Paper 23*, Washington: Worldwatch Institute, 1978.

The *Environmental Standard* assessment of dwellings acknowledged and awarded credit for the inclusion of recycled materials in new dwelling construction:[4]

> credit is awarded for specifying timer frame construction, and credit for specifying timber and timber products ... which are entirely either from well managed, regulated sources or of suitable reused timber.
>
> credit for specifying at least 50 percent by volume of material in roof covering, such as tiles or slates, to be from recycled or reused sources.
>
> credit for specifying at least 50 percent by volume of masonry material (e.g. brick, concrete block and stone) in walls to be from recycled or reused sources, and fit for the purpose.
>
> credit for specifying suitable uncontaminated demolition materials wherever appropriate in fill and hardcore.

The reuse of material from demolition waste is discussed in part in Deconstruction and Demolition: Recycling of Materials, refer to Annexe 3.6. For urban dwelling projects, toward which the thesis is predicated, the potential for existing, derelict or otherwise, buildings to be on a site is increased. On large scale sites and demolition waste that can be reused in a similar role, can as a last resort be crushed on site and recycled into aggregates for the new construction. On smaller sites the material may have to be removed from the site before being crushed.

The reuse of materials such as brick and roofing slates or tiles may assist in fulfilling the Contextual Significance of the Site benchmark, refer to Annexe 3.5. The reuse of a material on site have a very low embodied energy, which is particularly significant for materials such as brick which has a very high embodied energy in comparison to other materials. The embodied energy of the project will be reduced further by reducing the amount of material that has to be exported from the site, even if it is reused or recycled elsewhere. Using

---

[3] Collins, R. J., D. J. Harris and W. Sparkes. 'Blocks With Recycled Aggregate: Beam and Block Floors', Information Paper, London: Construction Research Communications Limited, 1998.
[4] Prior, J. J. and Paul B. Bartlett. *Environmental Standard – Homes for a Greener World*, Garston: Building Research Establishment, 1995.

reused materials within the same site for the external face of the dwelling will enable it to respond to the vernacular context of the site in terms of its materiality, if this is considered appropriate.

As materials such as brick have high embodied energies, their reuse should be encouraged through the matrix of benchmarks that defines the 'urban house in paradise'. This, as described previously, will also reduce the primary consumption of natural resources, and the consequent impacts that the mining, processing and transportation of those materials. The philosophy of *Factor Four* proposes that the use of natural resources be reduced by 75 percent. This value provides a target through which to propose and advance on the level of the use of reused or recycled materials that was advocated by the *Environmental Standard*.

In Drawn Study 5, it was proposed that wherever possible the materials from which the dwelling is constructed would be from recycled sources. One of the decisions for using concrete to create the thermal mass is that a proportion of the materials from which it is composed, the aggregates, can be derived from recycled sources.

As the potential proportion of material that can be derived form recycled sources will vary for different types of material, like the benchmark of recycled materials in the *Environmental Standard* the benchmark for the 'urban house in paradise' will vary for different materials.

For example, a typical mix of concrete would be 1:2:4 cement : fine aggregate : coarse aggregate. This is a ratio based on volume of material rather than mass. On the basis that 100 percent of the aggregate can be derived form recycled sources, then the ratio of the volume of concrete that will be material derived from recycled sources could be as high as 1:7, or 85 percent. However, the reuse of timber would not be that high. Unlike brick, timber cannot be crushed for reuse in aggregate if it cannot be reused directly. Therefore proportion of timber that can be reused or recycled will not be as great. Cellulose fibre insulation is available that is manufactured from recycled newspaper and therefore is the benchmark could be 100 percent for insulation, although that would dictate the use of specific materials.

The benchmarks proposed for the 'urban house in paradise' are targets, and may not be achievable in all situations. However, because they cannot be achieved on all sites should not mean that the benchmark is reduced, as the reuse of materials should be as great as feasible on sites where the opportunities exist.

Methodology of Assessment

Although it was an ambition of the thesis to quantify all of the benchmarks in dimensional terms, it is impossible to predict a generic numerical value the quantity of materials that will be in a dwelling, as the 'urban house in paradise' could be at once both a one person flat or a four bedroom terraced dwelling. Therefore for the benchmark of the quantity of material that is to be reused or recycled, it will be necessary to use a percentage. Once this benchmark is applied to a particular dwelling, or even dwelling type, it can then be translated into a quantitative value if necessary.

The level of materials in the dwelling to be derived from recycled or reused sources will be quantified by a percentage of their volume. The percentage benchmark can then be used to establish a minimum target figure of the volume of material once the generic benchmark can be applied to a specific dwelling or dwelling type. The benchmark can be assessed by firstly, determining the quantity of material within its structure, and secondly establishing if the benchmarked proportion of that material has been derived from recycled sources.

Conclusion

The benchmark established by the *Environmental Standard* sets an existing best practice level on which to base the benchmark. The speculative dwelling will, typically, use no recycled materials in its construction. As it has not been possible to establish any specific comparative dwellings demonstrating best practice that innovate upon this, Factor Four is used as the basis from which to propose a benchmark for the 'urban house in paradise'. This will set a level of 75 percent of the use of reused and recycled materials.

Therefore the proposed benchmarks for the criterion of Use of Recycled Materials is summarised in the table overleaf, in the context of the comparative dwellings.

	Reused or Recycled Material (percent)					
	Metal	Masonry	Roofing	Timber	Insul'n	Other
Typical UK speculative dwelling	0	0	0	0	0	0
European comparative: Envir'l Std	-	50	50	0	-	-
Drawn Study: 5	-	50	-	-	0	-
The 'urban house in paradise'	75	75	75	25	75	75

Use of Recycled Materials benchmark for the 'urban house in paradise'

3.34 Use of Renewable Materials

This is a criterion that has close interrelation to that of Use of Recycled materials, refer to Annexe 3.33. In situations where the use of reused or recycled materials is not viable, then primary raw materials will have to be used. In a context of the continual depletion of the earth's resources by unsustainable development, it is important that the matrix of the 'urban house in paradise' ensures that where the use of primary raw materials is necessary, they are from a renewable, and therefore sustainable, source. The only construction material that can be derived from renewable sources is timber.

Deforestation has many environmental consequences. These include less availability of plant life to sequester CO_2, which results in more CO_2 contributing to the greenhouse effect; there is a loss of habitat and therefore, potentially, species biodiversity; soil erosion is increased following the felling of trees, which can in turn lead to increased flooding.

The Building Research Establishment's *EcoHomes* assessment of dwellings acknowledges and awards credit for the inclusion of timber from a renewable source in new dwelling construction:[1]

> credit is awarded for specifying timer frame construction, and credit for specifying timber and timber products ... which are entirely either from well managed, regulated sources or of suitable reused timber.

A consequence of highlighting the advantages of using timber in construction may increase its use. This has many environmental benefits to sustainable construction. Timber is a renewable and therefore sustainable source. The carbon storing effect of timber from well-managed sources will contribute to alleviating the greenhouse effect, and therefore global warming, provided that the timber remains intact within the structure of the dwelling. For an intermittently occupied dwelling timber has a rapid thermal response, and also timber has good insulating qualities and, as has been demonstrated by precedent, timber frame structures can have good air tightness, both of which can lower the energy consumption of the dwelling.

The management of the source of renewably forested timber should also be considered. The planting of single species of trees does not encourage biodiversity, and therefore can result in forests with low ecological value. However, the use of timber from managed sources

---

[1] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.

will contribute to arresting the loss of species biodiversity elsewhere.

The *EcoHomes* assessment can be used as an indicator of best practice, as a specific comparative has not been determined. The benchmark can be interpreted that all of the timber within the dwelling that is not from a reused source should be from a renewable one.

The proportion of timber that should be provided through renewable sources will be informed by the remainder of the total that is not derived from reused or recycled sources. In this way, no timber used in the 'urban house in paradise' will contribute to a reduction of the planet's forests. The value proposed for the level of timber to be derived from reused or recycled sources is 25 percent; therefore the benchmark for the use of timber from renewable sources is 100 percent of the remainder.

Methodology of Assessment

As for the Use of Recycled Materials benchmark, it is impossible to predict a generic numerical value the quantity of materials that will be in a dwelling, as the 'urban house in paradise' could be at once both a one person flat or a four bedroom terraced dwelling. Therefore for the benchmark will be quantified as a percentage. Once this benchmark is applied to a particular dwelling, or even dwelling type, it can then be translated into a quantitative value if necessary.

The level of materials in the dwelling to be derived from renewable sources will be quantified as a percentage of their volume. The percentage benchmark can then be used to establish a minimum target figure of the volume of material once the generic benchmark can be applied to a specific dwelling or dwelling type. Therefore the benchmark can be assessed by firstly, determining the quantity of material within its structure, and secondly establishing if the benchmarked proportion of that material has been derived from renewable sources.

Conclusion

The benchmark established by the *EcoHomes* assessment sets an existing best practice level on which to base the benchmark. As this demands that all of the timber used within the dwelling be derived from certifiable renewable sources, it is not possible to benchmark an improvement. Therefore the proposed benchmarks for the criterion of Use of Recycled Materials is summarised in the table overleaf, in the context of the comparative dwellings.

	Timber from Renewable Source (percent)
Typical UK speculative dwelling	0
European comparative: *EcoHomes*	100
Drawn Study: 5	-
The 'urban house in paradise'	100

Use of Renewable Materials benchmark for the 'urban house in paradise'

3.35 Utilisation of Local Resources

Sustainability extends beyond the boundaries of just ecology; it also encompasses social and economic dimensions. The utilisation of local resources in the construction of the 'urban house in paradise' is one criterion that will reflect this.

Different modes of transport consume various levels of energy per unit mass of material transported, with corresponding varying levels of emissions. For example Baird gives a value of 1.25 kWh per tonne per kilometre for road transport, compared to 0.17 kWh per tonne per kilometre for rail.[1] The consequent emissions arising from different modes of transport is shown in the following table.

Emission Type	Emissions by Mode of Transport ($g.t^{-1}.km$)		
	Road	Rail	Water
Carbon dioxide	211	102	33
Carbon monoxide	0.90	0.02	0.11
Hydrocarbons	0.68	0.01	0.05
Nitrogen dioxide	2.97	1.01	2.26
Particulate matter	0.39	0.01	0.02
Sulphur dioxide	0.20	0.07	0.04

Pollution Emissions by Different Modes of Transport

Transportation can account for a significant proportion of the overall embodied energy content of materials. For example, if a typical brick weighs 2.45 kg,[2] the transportation of one brick by lorry over one kilometre, based on Barid's value above, will require 0.03 kWh of energy. If the embodied energy content of brick, which accounts for the energy used in the production and not transportation of materials, is 1.2 $kWh.kg^{-1}$,[3] the embodied energy of a single brick will be 2.94 kWh. To transport one tonne of bricks over one kilometre will consume 1.25 kWh of energy; the embodied energy used in the production of these 408 bricks will be 1,199.5 kWh. Therefore if the bricks are transported over 960 kilometres the energy used in transportation will equal that used in their production. To put this another way, if the bricks are transported 240 kilometres, the overall embodied energy of the brick will

[1] These values are based upon transportation in the United States of America, but are valid for demonstration of relative energy consumption between different modes of transport. Baird, G. 'The Energy Requirements and Environmental impacts of Building Materials' in Dawson, A. (ed.) *Architectural Science: Its Influence on the Built Environment*, Geelong: Deakin University, 1994.

[2] This is based on the assumption that brick has a density of 1,750 $kg.m^{-3}$ and a volume of 0.0013975 m^3, from the dimensions 100 by 215 by 65 mm.

[3] Szokolay, S. V. *Environmental Science Handbook*, London: The Construction Press, 1980.

be increased by a quarter; if the lorry transporting the bricks returns empty, the effective distance between the brickworks and site need only be 120 kilometres, or 75 miles, to increase the embodied energy of the bricks by 25 percent.[4]

Therefore using local materials, provided that they fulfill the other criteria of the 'urban house in paradise' governing the sustainability of materials to be used in the dwelling, will help reduce overall embodied energy content, and therefore emissions arising from transportation also. Research currently being conducted by the Building Research Establishment suggests that the energy consumption and consequent emissions of site workers travelling to and from site can have a significant impact on the overall embodied energy of a building.[5] However, resources go beyond only the material; whilst using local materials will contribute to the local economy, the utilisation of human resources will also benefit both social and economic sustainability.

As identified this must not be at the expense of other benchmarks within the matrix, especially those with a higher significance rating. For example, whilst the use of local materials might initially seem advantageous, there may be more serious ecological disadvantages that outweigh any benefits if, say, the processes of extracting the locally sourced materials are particularly energy intensive, or have other serious ecological impacts.

Speculative house builders quite frequently use local human resources for at least part of the construction process. Through procuring the construction using a large number of subcontractors, companies are often used that are local to a specific project. In the Millennium Community at Allerton Bywater it was a specific intention of the winning submission, an therefore Drawn Study Three which was developed as a part of that project, that where possible the construction would ustilise local personnel; this was specifically orientated toward training.

A quantitative value as to what constitutes 'local' could be derived from the Beddington Zero Emissions Development, or Bedzed, in the London Borough of Sutton. Designed by the architect Bill Dunster for the Peabody Trust, this solar 'urban village' includes 100 houses and over 200 workspaces. A proviso was established that all materials used to construct the building should be sourced from within 35 miles of the site.[6] This value sets a benchmark for

---

[4] The methodology used in this analysis is based upon one in Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.

[5] Personal communication with Suzy Edwards of the Sustainable Construction unit of the Building Research Establishment, 5 October 2000.

[6] Hartman, Hattie. 'Eco Soundings', *Building Design*, 23 June 2000.

the location of the source of materials used to construct the 'urban house in paradise'.

Methodology of Assessment

The benchmark could be established in the form of a qualitative response to whether or not sufficient consideration has been given to maximising the use of local resources. For example, have all materials used in the construction of the dwelling been derived from local sources? Also, has the project maximised, where appropriate, the use of local human resources? However, this does not substantiate what is defined by the term 'local'. Furthermore, it is a specific ambition of the thesis to quantify the benchmarks in dimensional terms.

Alternatively, a value could be proposed from within which material and human resources should be derived; this would limit the implication of transport use, with consequent energy consumption and pollution. For example, a value of 45 kilometres would constitute an innovation upon the benchmark proposed by the Bedzed.

Conclusions

Therefore, the values for the benchmarks of Utilisation of Local Resources for the 'urban house in paradise', seen in the context of the other comparative benchmarks of the typical speculative dwelling, European comparative of best practice and Drawn Study 3, is proposed in the table below:

	Utilisation of Local Resources	
	Materials	Human Resources
Typical UK speculative dwelling	-	Yes
European comparative: Bedzed	56	Unknown
Drawn Study: 4	-	Yes
The 'urban house in paradise'	45	45

Utilisation of Local Resources benchmark for the 'urban house in paradise'

3.36 Water Consumption: Construction

In 1995 approximately 17,500 million litres of water were abstracted each day to supply the public in England and Wales.[1] The domestic consumption of water in the United Kingdom is approximately 160 of the per capita national consumption of 570 litres per person per day. Water, like other naturally occurring materials, is a finite resource, and not available in unlimited quantity. Energy is required to treat and provide it, and to treat the subsequent wastewater, all of which has a consequent impact through fossil fuel consumption and emissions.

Water in used in many situations in the construction industry. For example, the manufacture of 1 tonne of cement requires 3,000 litres of water, and the manufacture of 1 tonne of steel consumes 300,000 litres. Building materials also consume similarly large quantities of water; for example cement requires approximately 3,600 litres of water per tonne of dry cement powder. For the purposes of quality, the water used in these materials is mains water, of drinkable quality. The purification and delivery of this water consumes energy, and therefore fossil fuels, and creates pollution emissions.[2]

Standard values of the ratio of water to cement, for example, can be used to determine the quantity of water consumed in producing the materials that are used to construct a dwelling.[3] The volume of concrete in the ground floor slab can be established, and the ratio of water to cement in a typical mix can be used to establish the quantity of water in the slab. This process was conducted to establish the quantity of water used in the construction of a typical 3 bedroom semi-detached house; insufficient data was available to establish the quantity of water used in the production of all the building materials, such as in the manufacture of bricks, therefore the study was restricted to the on site processes. It was determined that the construction of the envelope of the dwelling consumed approximately 2,863 litres of water, or 34.1 $l.m^{-2}$.

The increased prefabrication and emphasis on rapid construction, by organisations such as the Movement for Innovation and Construction Best Practice Programme, is perceived as achievable in part through reducing the amount of wet trades. If the external walls of the typical dwelling considered above were built in a prefabricated material that consumed no

---

[1] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.
[2] Shouler, M. C. and J. Hall. *Water Conservation*, Garston: Building Research Establishment, November 1998.
[3] Chudley, R. *Building Construction Handbook*, Oxford: Newnes, 1988.

water in its construction on site, such as a double skin of timber frame clad in weather boarding, the consumption of water would be reduced to 1,174 litres, or 13.9 $l.m^{-2}$.

The consumption of water that would be used on site in the construction of Drawn Study 4 was calculated using the same methodology. The quantity was determined as 948.9 litres, or 9.5 $l.m^{-2}$. This reduction was primarily due to the use of epoxy bonding in the construction of the walls.

The philosophy of *Factor Four* proposes that the use of natural resources be reduced by 75 percent. This ambition can be used as a target through which to propose and advance on the level of water consumed in the construction of a typical dwelling. If the typical level is taken as 34.1 $l.m^{-2}$, as established above, this would equate to a benchmark of 8.5 $l.m^{-2}$.

A disadvantage of the reduction of wet trades is that achieving a very airtight structure may prove more difficult. The Vales used wet trades within their Southwell to create airtight walls and floors. However, it has been proven that timber frame can achieve very high standards of air tightness.[4]

Methodology of Assessment

The assessment against the benchmark will be based on the quantity of water consumed in the construction of the dwelling on site. Due to limited information, it has not proved possible to determine the quantity of water that is consumed in the production of a sufficiently wide range of building materials to include the water consumed in the production of materials before they arrive at site. Should such information be determined, for example in further research, this could be integrated into the assessment.

The overall quantity of water can be determined through calculating the volume of the relevant materials, such as mortar or cement, and using the specified mix to determine the proportion of water within that material. The volume of water can be converted into a litre in figures, as 1 m^3 of water equates to 1,000 litres. Dividing the total quantity of water by the total net floor area will establish the benchmark performance.

[4] BRECSU. 'Review of Ultra Low Energy Homes – A Series of UK and Overseas Profiles,' *General Information Report Number 38*, London: HMSO, February 1996.

Conclusions

Therefore, the proposed value of the benchmark of Water Consumption: Construction for the 'urban house in paradise', in the context of the comparative standards, is summarised in the table below. Due to limited data available on this criterion, it was not possible to cite a comparative dwelling that demonstrates European best practice.

	Water Consumption ($l.m^{-2}$)
Typical UK speculative dwelling	34.1
European comparative:	-
Drawn Study: 5	9.5
The 'urban house in paradise'	**8.5**

Water Consumption: Construction benchmark for the 'urban house in paradise'

3.37 Water Consumption: Inhabitation

In the United Kingdom, the mean water usage for domestic purposes is 160 litres per person per day.[1] This figure can be broken down to demonstrate to what proportion the various functions of habitation contribute to this value, which will assist in determining where the greatest savings may potentially be achieved:

Function	Percentage of total use	Litres per person per day
General usage	35	56
Flushing toilet	32	51
Baths and showers	17	27
Washing machines	12	19
Outdoor use	3	5
Dishwashing	1	2
Total	100	**160**

Domestic water consumption, by function[2]

This total consumption follows an 88 percent increase in household water use over the last 36 years.[3] The trend of increasing use is predicted to continue, at a rate between 10 and 20 percent between 1990 and 2021; this is assuming a scenario of a medium growth without accounting for effects due to climate change. The predominant cause is due to an increase in dishwashers and other domestic appliances.[4] If the potential effects of climate change are taken into account, in domestic use this will primarily have an impact through increased frequency of showers and garden watering; the predicted rise will increase by a further 4 percent.[5] Another factor for increases in water use is demographic change, due to the decreasing occupation densities of dwellings. As the number of occupants per dwelling decreases, the water consumption for each inhabitant within that dwelling increases.[6]

The solution to this increased consumption, as well as the increasing shortages of water in the south and east, could be provided through increasing the capacity of supply through, for

---

[1] The Water Services Association. *Waterfacts '97*, London: WSA, 1998.
[2] Percentage figures supplied by North West Water.
[3] The Water Services Association. Op. Cit.
[4] Roaf, Dr Susan and Dr Peter Spillett, in Roaf, Dr Susan and Vivien Walker (eds). *21AD : Water*, Oxford: Oxford Brookes University, 1997.
[5] Department of the Environment. *Review of the Potential Effects of Climate Change in the United Kingdom*, London: HMSO, 1996.

example building new reservoirs, or by reducing consumption. However, building reservoirs is expensive, and can have significant impacts upon the environment, including habitat destruction. Furthermore, it should also be borne in mind that water, like other naturally occurring materials, is a finite resource, and not available in unlimited quantity.

For the water consumption of a family of four, of around 600 litres per day, 120 kWh of energy is required per year to provide it, and 100 kWh per year to treat the subsequent waste water. Generating this energy releases 200 kg of CO_2 into the atmosphere each year.[7] In addition to this will be the energy consumption, and resultant emissions, of the energy used to heat the water within the dwelling. Therefore, water conservation will not only contribute to the reduction of a resource use, but also to a reduction in energy consumption and emissions both in supplying the potable water, heating it within the dwelling and removal as sewage.

To a significant extent water consumption is affected by the usage patterns of the inhabitants themselves, and savings in this respect would be achieved through communicating the value of water conservation, both in economic and ecological respects. However, measures can be taken in the design and specification of the dwelling to ensure a degree of water conservation over current levels of consumption.

For example, the United States National Plumbing Standards, which went into effect in 1992, cut the typical mean American use figure of 303 litres per person per day by 35 percent, to approximately 197 litres per person per day. This is the reduction that would be achieved through fitting the most inefficient plumbing fittings permitted under the Standards, for example a 5.7 litres per flush toilet, and a 9.5 litres per minute showerhead and taps.[8]

From the above it is evident that significant savings can be achieved through increasing the efficiency of toilets, taps and showers, as these fittings relate to the functions that are the second and third greatest consumers of water. In addition, more efficient taps will also assist in reducing the consumption level of general usage which the largest category of consumption from, for example, washing food.

---

[6] Griggs, J. C., M. C. Shouler and J. Hall. 'Water Conservation and the Built Environment,' in Roaf, Dr Susan and Vivien Walker (eds). *21AD : Water*, Oxford Brookes University, 1997.
[7] Shouler, M. C. and J. Hall. *Water Conservation*, Garston: Building Research Establishment, November 1998.
[8] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998.

Water Bylaws state that from the beginning of 1989, all new WC installations must have a maximum capacity of 7.5 litres per flush.[9] If this were a Swedish 3.0 litre per flush model,[10] the saving would be approximately 60 percent, or 63.6 litres per household per day. These Bylaws are currently under review, under recommendations by the Water Regulations Advisory Committee, that include the reduction of the maximum flush to 6 litres.[11]

The *Environmental Standard* awards credit for WCs with a maximum flushing capacity of 6 litres per flush or less, or for the inclusion of a rainwater butt with a maximum capacity of 350 litres, and a minimum of 60 litres per dwelling. It also acknowledges that a well-designed WC can operate at a capacity as low as 3.5 litres.

In the *EcoHomes* assessment of dwellings this was updated to include specific levels of consumption, based upon the number of bedrooms within the dwelling. The most inefficient standard that would receive a credit was 45 m^3 per bedroom per annum, and the most efficient standard was proposed as 25 m^3 per bedroom per annum.[12] These values can be converted, using an assumed occupancy per bedroom of 1.5 people, to 82 litres per person per day and 45 litres person per day.[13]

The typical discharge rate for a conventional showerhead and is between 0.3 and 0.5 litres per second; a low-flow rate shower can reduce this to below 0.2 litres per second. The Building Research Establishment Information Paper *IP 1/87* provides figures on the average number of baths and showers taken per person per week in the United Kingdom, of 1.6 per person per week. Figures are also provided for the average water consumption per bath and shower, of 90 litres per bath and 21 litres per shower.[14]

If the typical shower consumes 21 litres of water at a mean flow rate of 0.4 litres per second, then fitting a low-flow rate shower of 0.2 litres per second will mean that the typical shower will consume 10.5 litres of water. *GIR 53* recommends the use of aerating taps for use in basins and shower to cut down water demand, with a flow rate of 0.1 litres per second;[15] this would equate to a consumption per shower of approximately 5.3 litres. If showers and baths are

---

[9] Department of the Environment. *UK Model Water Bylaws (1986)*, London: HMSO, 1986.
[10] Flush capacity of Ifo Aqua wc, in Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.
[11] Griggs, J. C., N. J. Pitts, J. Hall and M. C. Shouler. *Water Conservation: A Guide for Design of Low-Flush WCs*, Garston: Building Research Establishment, August 1997.
[12] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.
[13] 1 m^3 of water equates to 1,000 litres.
[14] Building Research Establishment Information Paper IP *1/87*, Garston: Building Research Establishment, 1987.

taken on average 1.6 times per person week, this would lead to a consumption of 8.4 litres per person per week for cleansing. However, it has been demonstrated that households with showers use them more often than households without showers will take baths. If, therefore, to be prudent one assumes that each person takes a shower each day, then the consumption will be 5.3 litres per day.

The 'Min-Use shower, first marketed in the early 1980s in the United States, demonstrated the savings that can be achieved through the highly efficient design of sanitary fittings. Based on the concept of Buckminster Fuller's mist showers that were developed for submarines, the 'Min-Use' shower's 0.03 litre per second spray is propelled by a stream of low-pressure warm air.[16] This flow rate is 21 percent that of the conventional 0.2 litre per second low flow-rate shower head of the standard United Kingdom fitting, a reduction of 79 percent, or, potentially, 44.5 litres per day if showers are always taken and never baths. In addition, the 'Min-Use' consumed only 1 to 2 percent as much electricity in running the blower over heating less water. Other research in the United States has shown that the use of low-volume showerheads can save approximately 27 litres per person per day; this equates to a hot water energy saving of 444 kWh per person per year for water heated by gas, or 388 kWh per person per year for water heated by electricity.[17]

The Vales, in their prediction of the water consumption at their house in Southwell, Nottinghamshire, estimated the water consumption from showering. This was based upon a flow rate of 6 litres per minute[18] and a duration of 4 minutes; they also assumed one shower per person per day resulting in a consumption of 24 litres per person per day for cleansing.[19] A shortcoming of this analysis, which was the total value proposed for personal hygiene, is that it made no account of the water consumed through cleansing such as face or hair washing in a sink and hand washing in a sink, including that after using the WC. This was rectified in the Vales' analysis made after the dwelling had been inhabited for five years. The consumption from showering proved to be significantly less, with the average rate being three showers per day, as opposed to the predicted five. The water consumed per shower was measured at 15.7 litres, including any run off of cold water at the start. The revised value is given as 4 showers of 20 litres per person per day. The value proposed for the occasional

---

[15] BRECSU. 'Building a Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, London: Construction Research Communications Limited, October 1998.
[16] Weizsacker, Ernst von, Amory B. Lovins and L. Hunter Lovins. Op. Cit.
[17] Shouler, M. C. and J. Hall. Op. Cit.
[18] This value is based upon the minimum flow rate that could be achieved with a conventional showerhead fitted with a flow restrictor.
[19] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.

use of hand basins is 5 litres per person per day.[20]

The rate of the flow of water through taps can also be reduced to minimise overall consumption. Aerating taps, as recommended by *GIR 53* can be used on basins, with a maximum flow rate of 0.1 litres per second, as opposed to 0.2 litres per second for a standard tap. The maximum discharge rate for a spray tap basin is 0.06 litres per minute.[21]

The consumption of water through washing dishes can also be predicted. The Vales suggest a value based on two washes per day with a five litre capacity washing up bowl. In their five-person dwelling this results in a consumption of 2 litres per person per day; this value is substantiated by that of the Water Services Association data, summarised in the table at the beginning of this Annexe.[22] The increase in domestic appliances, such as dishwashers, has already been cited as a cause of the increase in domestic water consumption. If a typical dishwasher consumes 17 litres per wash,[23] and if one assumes the mean occupancy of a dwelling of 2.4, this 8 place setting appliance would be used every 3.33 days; this would equate to a consumption of 2.13 litres per person per day. This shows a slight increase in the per capita consumption.

Low water use washing machines and dishwashers could both contribute to reducing existing consumption levels and future increases. Research suggests that these could save 3.8 and 6.4 litres of water per day per capita respectively.[24] However, the matrix of the 'urban house in paradise' cannot ensure that its inhabitants purchase such an appliance. An alternative, depending upon the procurement and ownership of the dwelling, might be to arrange favorable leasing agreements or their purchase at the time of the purchase of the dwelling to encourage their use.

The Vales make a prediction for the consumption of water by washing machines, of 6 litres per person per day. This value is based on their empirical analysis of the water consumption of a number of washing machines. The mean value is 97 litres per wash, although the value used in their prediction is 70 litres per wash. This value is then multiplied by three washes per week, and divided across the five occupants of the dwelling, to give a consumption of 6 litres per person per day.[25] This figure could be adapted into a more generalised scenario, as this is based on an occupancy of five people per dwelling. If one assumes that for the mean

[20] Ibid.
[21] BRE Housing Design Handbook, Garston: Building Research Establishment, 1988.
[22] Vale, Brenda and Robert. Op. Cit.
[23] Manufacturer's data for Tricity Bendix DH 086 'EcoSave' dishwasher.
[24] Griggs, J. C., M. C. Shouler and J. Hall. Op. Cit.
[25] Vale, Brenda and Robert. Op. Cit.

occupancy of 2.4 people per dwelling, 2 washes per week are made, this would equate to a per capita consumption of 8.3 litres per day.

Whilst there are precedents in existence, the use of greywater recycling within the dwelling is still relatively new; the Building Research Establishment is currently assessing the implications to health and hygiene of the use of grey water within dwellings. For example, the reuse of wastewater from baths, sinks and basins to flush WCs may have a detrimental effect on the cistern. However, the use of rainwater could have significant effects on the reduction in delivered water consumption. For example, *Factor Four* projects that delivered water supplies could be cut by 90 percent through using rainwater for all fixtures with the exception of taps.[26] In an urban context, however, there may be limitations on the available roof space for run-off collection, and the space requirements for the storage of water for during drier seasons is likely to have an impact. For example, for a four person dwelling designed by the Vales to have sufficient supply, the storage capacity was 25,000 litres.[27] This equates to storage per person of 6,250 litres, which may prove to create significant design challenges for urban housing design in high density locations.

For example, if the overall consumption benchmark of consumption is 160 litres per person per day is achieved, for a mean household size of 2.4 people, the area of collecting surfaces required to fulfil this demand with rainwater can be determined using the following equation:[28]

$$\text{Area } (m^2) = (x \times n \times 365.25) / (r \times 0.66)$$

where,

x = daily water consumption per person ($l.p^{-1}.d^{-1}$)
n = number of inhabitants in the dwelling
r = annual rainfall (for example 950 mm)

This gives a roof area of 212.5 m^2; this can be seen in comparison to the roof area of a typical 3 bedroom semi-detached dwelling, which is in the region of 49 m^2. If, however, the consumption is substantially reduced, which the benchmark of the 'urban house in paradise' will aim to achieve, then the required area will not be this high. However, in *GIR 53*, the Vales envisage that additional collection surfaces may be required in addition to the roof for an autonomous dwelling, based upon the standard plan and area of a typical housing association dwelling.

---

[26] Weizsacker, Ernst von, Amory B. Lovins and L. Hunter Lovins. Op. Cit.
[27] BRESCU. Op. Cit.
[28] Derived from Vale, Brenda and Robert. *The Autonomous House – Design and Planning for Self-Sufficiency*, London: Thames and Hudson, 1975.

In terms of benchmark reductions, as water is a resource, *Factor Four* philosophy would demand a reduction of current typical consumption of 160 litres per person per day by 75 percent, which would equate to a new consumption level of 40 litres per person per day. *GIR 53* proposes that an autonomous dwelling with full rainwater storage would have a consumption level of 34 litres per person per day; allowing for a water-flushed, as opposed to composting, WCs the consumption would be less than a third of the conventional level, and therefore less than 54 litres per person per day.

This vale is also borne out by the Vales analysis of the consumption of their dwelling in Southwell, both for the design and occupied analysis. This is summarised in the following table:[29]

Function	Consumption ($l.p^{-1}.d^{-1}$)	
	Design prediction	Occupied
Drinking and cooking	5	5
Flushing toilet	0	0
Personal hygiene (showers)	26	16
Personal hygiene (washing)	-	5
Washing machines	6	6
Dishwashing	2	2
Total	39	34

Design prediction and actual consumption of water for Vale's dwelling Southwell

This value discounts the consumption from outdoor use, based on the assumption that waste water from the dwelling, which is disposed of through a soakaway into the site, would be used for this purpose. Because the system is fully autonomous, no account has to be made for losses arising within the mains system.

The Vales' dwelling is an example of one for which all of the consumption demands are meet from rainwater collection. The area of collecting surfaces is large, at 142 m^2 including the conservatory. However, the rainfall in Nottinghamshire is relatively low, and the dwelling has never approached running out of stored water, the capacity for which is 30,000 litres, or 6,000 litres per person, stored in the basement. The Vale's attribute the ability to harvest all of the dwelling's requirements from rainwater to the very low consumption rate of the five people who inhabited the dwelling.

The submission of the first Millennium Communities Competition at Greenwich, designed by the Swedish-based architect Ralph Erskine (1914-) and the British architects Hunt Thompson, proposed a reduction of water demand by 30 percent. The GMV team proposed a value of the typical water consumption by households in the United Kingdom, in order that they could measure the success of their reduction measures; this value was also 160 litres per person per day.[30] Their benchmark reduction would equate to a new consumption level of 97 litres per person per day. Such a cut in demand was envisaged for 25 percent of the units, those that are individual dwellings, is generated through the recycling of greywater from bath and wash hand basins for WC flushing, and rainwater collection for external use.

One scenario that could be developed to benchmark the level of consumption of the 'urban house in paradise' is assuming the use of stored rainwater for external use, clothes washing and WC flushing, or uses that can be identified as not using any taps, in response to the issue of health and hygiene. This would reduce daily consumption by a total of 47 percent, or 75.2 litres per person per day. Furthermore external use is likely to be lower in urban areas, due to the higher density of dwellings and reduced garden area, if gardens are present, and also through reduced car ownership leading to less water used for car washing. The proposals by the Llewelyn-Davis density matrix, refer to Annexe 3.8, for parking provision in urban areas is between 1.5 and less than 1 space per dwelling, as opposed to the current typical suburban provision of 2 spaces per dwelling.[31]

Another methodology of benchmarking would be to take the figure of the daily level of human consumption, which has the highest need for purity, and use this to determine a benchmark for mains supply to the dwelling. A second benchmark can be created for the consumption for other uses that is supplied by grey and rain water sources. As the secondary uses that consume grey and rain water could be described as consuming a renewable source, it is still important to benchmark the rate of consumption at an innovative level; in addition, cutting down the rate of consumption would also cut down the need for storage. If, at a later date, sufficient confidence is gained in the use of rainwater for human consumption for it to be included by house builders and housing associations in their dwellings, and the issue of storage has not proved to be problematic, then the two benchmarks can be combined into one that demands the full supply to be provided by grey

---

[29] Complied using data in Vale, Brenda and Robert. Op. Cit.
[30] English Partnerships. *Greenwich Millennium Village: Draft Benchmarking Manuel: Energy, Water Consumption and Constructional Efficiency Targets (second draft)*, unpublished, 5 May 1999.
[31] Hattersley, Lia. 'Density Formula Packs Them In,' *Building Design*, 18 July 1999.

and rain water sources.

Research suggests that without extensive filtration and purification, grey water use in domestic situations would be best limited to WC flushing; even so, filtering and purifying will have to take place, because of potential accidental contact with WC water from children and pets drinking water in the bowl.[32] If, therefore, grey water use within the 'urban house in paradise' is limited to WC flushing, it is important to ensure that the benchmarked reductions of functions that supply grey water to the WC, for example showers and basins, will still provide sufficient water to fulfill the needs of the benchmarked WC consumption. Should this fall below the level of WC use, it can be backed up by rainwater, providing that sufficient storage is available for rainwater. Research has shown that under current use patterns, on average 42 percent of all water supplied to a property is discharged as grey water, and toilet flushing accounts for 34 percent, and therefore the system is viable.[33]

Composting toilets can further reduce the benchmark of water consumption. Whilst not contributing to a further reduction of water consumption, as they are replacing a function that would use a recycled supply, they could facilitate further reductions in other uses. Composting toilets could be used irrespective of the provision of grey water by other functions within the dwelling, and therefore allow them to be benchmarked below the level of WC demand, whilst not increasing the demand on rainwater storage for a back up supply to the WC. Also, composting toilets will reduce the wastewater output of the dwelling, and therefore contribute to further reduction in energy consumption and consequent emissions, created by sewage processing, and also pollution associated with sewage disposal. They will, however, be subject to a customer acceptance if they are to be used in speculative and social housing projects. Research has been undertaken into the potential acceptability by the public of water saving products and techniques,[34] full composting toilets were rated with an acceptability of three out of five, or 'reasonable.'

If the notion of using composting toilets is considered too innovative an alternative value can be used based on a low flush toilet. The 51 litres per person per day used to for WCs in the table at the start of this Annexe can be used to conclude that if an average flush is assumed to be 7.5 litres, as became regulatory in 1989, the average number of flushes is 6.8 per person each day. Therefore a 3.0 litre low flush toilet would consume 20.4 litres per person per day. An alternative to this would be to use the grey water from the showers, sinks and

---

[32] Hill, Matthew. 'Grey Water Recycling: Experiences in Housing,' in Roaf, Dr Susan and Vivien Walker (eds). *21AD : Water*, Oxford: Oxford Brookes University, 1997.
[33] Murrer, John. Grey water Treatment and Reuse,' in Roaf, Dr Susan and Vivien Walker (eds). *21AD : Water*, Oxford: Oxford Brookes University, 1997.

washing machine, filtered and stored, to flush the WC; this would mean that in effect its consumption would be zero litres per person per day, provided that there is sufficient grey water available. The consumption from the showers, sinks and washing machine in the benchmark given below is 35.3 litres per person per day, which should in theory be sufficient to provide the 20.4 litres per person per day for the low flush toilet. Even allowing for 25 percent losses in the cycle,[35] this would leave 5 litres per person per day for outdoor use, such as watering the garden.

The Canadian Residential Energy Efficiency Database provides a percentage breakdown of water usage by dwellings.[36] It attributes 5 percent of the total usage to drinking and cooking; therefore, of the typical consumption of 160 litres per person per day, the consumption by drinking and cooking translates as 8 litres per person per day. However, Smith proposes a value for drinking and cooking of 5 litres per person per day.[37] Assuming a mean of these two values would suggest a consumption of water that needs to be of 'drinking water quality' of 6.5 litres per person per day.

In Drawn Study 4, the proposal is made to collect rainwater for external use. However no specific water saving features were included to reduce consumption within the dwelling. On the basis of the typical consumption identified at the start of this Annexe, as no water saving measures are included in the dwelling, the benchmark of overall consumption will be 160 litres per person per day. This can be broken down as 155 litres per person per day of mains water and 5 litres per person per day of rainwater.

Therefore, on the basis of the analysis above, benchmarks for the various sources on consumption caused fulfilling the rituals of dwelling can be derived. The best practice comparatives will be based upon the highest standard of the *EcoHomes* assessment and the Vale's dwelling, which is fully autonomous from the mains water supply and sewage. The benchmarks proposed for the domestic water consumption during the period of inhabitation of the 'urban house in paradise' is summarised in the table overleaf.

---

[34] Griggs, J. C., M. C. Shouler and J. Hall. Op. Cit.
[35] Such losses would include evaporation, loss as steam, and to towels as the inhabitants dry themselves after cleansing.
[36] Residential Energy Efficiency Database website, 21 July 1999: www.its-canada.com/reed
[37] Smith, G. *Economics of Water Collection and Waste Recycling: Working Paper 6*, Cambridge: University of Cambridge, 1973.

Function	Consumption ($l.p^{-1}.d^{-1}$)	
	With Low Flush WC	With Composting
Drinking and cooking	6.5	6.5
WC	20.4	0
Personal hygiene (showers)	20	20
Personal hygiene (washing)	5	5
Washing machines	8.3	8.3
Dishwashing	2	2
Total	62.2	41.8

Proposed water consumption benchmarks for the 'urban house in paradise'

The reduction of mains water consumption will create significant savings in terms of energy consumption and CO_2 emissions generated through processing and providing it. If, from above, 220,000 litres of water takes 120 kWh and 109.1 kg of CO_2 emission to deliver it, and if the reduction of mains water consumption by the 'urban house in paradise' is 153.5 litres per person per day, this will save in the region of 0.08 kWh of energy, and 0.07 kg of CO_2 emission per person per day. If the mean occupancy of the typical dwelling in the United Kingdom is 2.4 person,[38] this will equate to an energy saving of 70.1 kWh per dwelling per annum, and CO_2 emission reduction of 61.3 $kgCO_2$ per dwelling per annum.

Methodology of Assessment

This will be based on prediction, similar to the methodology used by the Vales to predict the consumption in their dwelling in Southwell. This will allow account to be made water saving initiatives, such as low flush or composting toilets and low water consumption appliances. A minimum consumption of potable water consumption will be assumed, of 6.5 litres per person per day, for cooking and drinking.

The potential quantity of rainwater available can be determined from the annual average rainfall for the dwelling's location and the area of collection surfaces.[39] To account for annual

[38] Office for National Statistics. Living in Britain - *Results form the 1995 General Household Survey*, London: HMSO, 1996.
[39] Vale, Brenda and Robert. *The Autonomous House – Design and Planning for Self-Sufficiency*, London: Thames and Hudson, 1975. This methodology used in this paragraph is based on a calculation for the required area of collection to fulfil the water demands of a three person dwelling with that text.

variation, the minimum expected rainfall is determined by assuming a value two thirds that of the average. To account for water lost through evaporation, the area of collecting is reduced by 10 percent. As 1mm.m^{-2} of rainfall is the equivalent of 1 litre.m^{-2}, the quantity of rainwater available is determined by multiplying the area of collecting surfaces by the rainfall; this annual value is then divided by 365.25 to determine the daily quantity of rainwater potentially available. This can be quantified by the following equation:

$$y = (0.9 \times \text{area of collecting surfaces} \times {}^{2}/_{3}\,\text{annual rainfall}) / 365.25$$

or,

$$y = (1.8 \times \text{area of collection} \times \text{rainfall}) / 1095$$

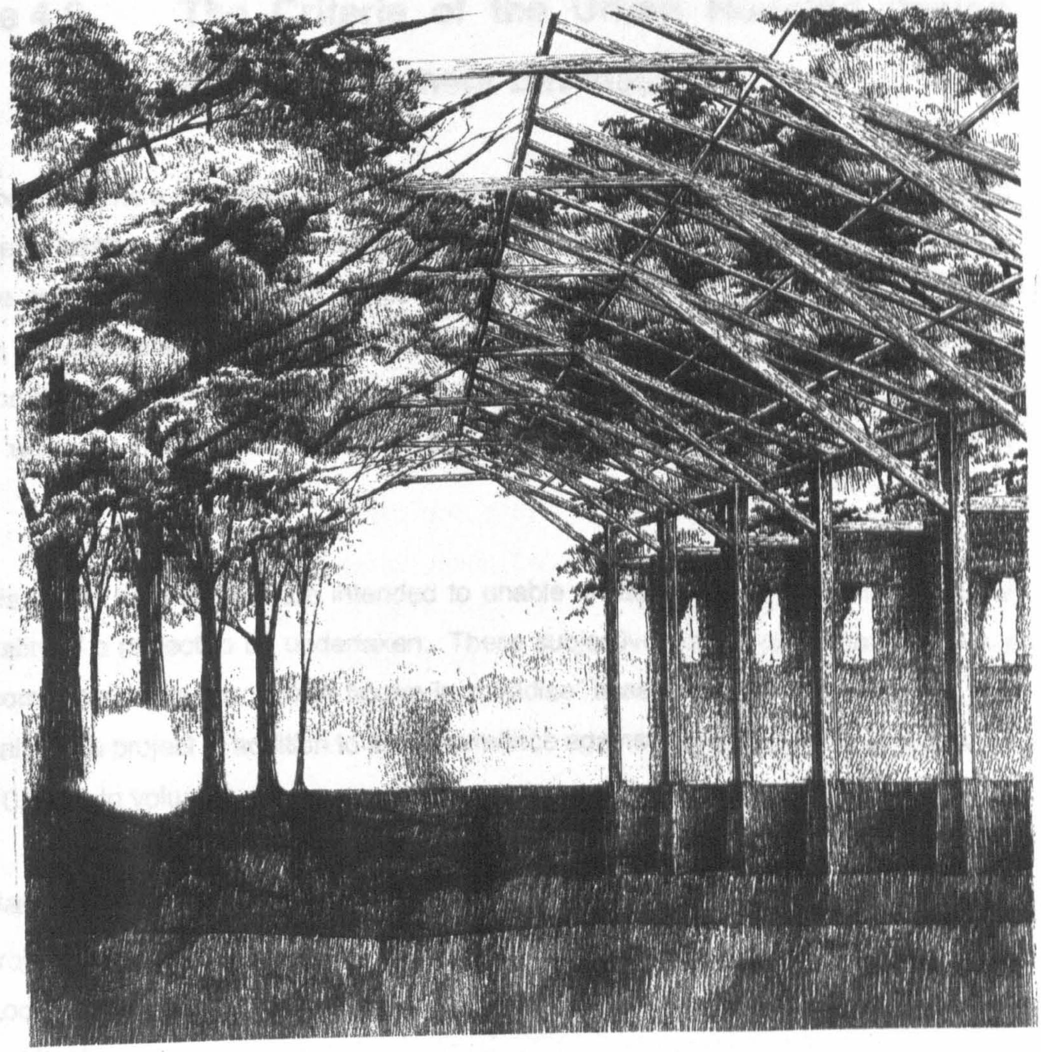
Conclusion

Therefore, the proposed benchmark for the criterion of Diversity, seen in the context of the other comparative benchmarks of the typical speculative dwelling and European comparative of best practice, is proposed in the table below:

	Water Consumption ($l.p^{-1}.d^{-1}$)		
	Mains	Rain and grey	Total
Typical UK speculative dwelling	160	0	160
European comparative: Southwell	0	34	34
Drawn Study: 4	155	5	160
The 'urban house in paradise'	6.5	35.3	41.8

Water Consumption: Inhabitation benchmark for the 'urban house in paradise'

Annexe 4



The Criteria of the Urban Housing Design and Procurement Database

Annexe 4.0 The Criteria of the Urban Housing design and Procurement Database

This annexe contains a full listing of the criteria developed for the Urban Housing design and Procurement Database (UHDPD), a database of urban housing projects, on a European and world wide scale, that assess each project in terms of both objective, or quantitative, and subjective, or qualitative, criteria. It was developed during the initial stages of the research project, and therefore forms a parallel study to that part of the thesis. The criteria within the database were a source for considering the criteria that defines the 'urban house in paradise'.

The criteria in the third section are intended to enable an assessment of the architectural design quality of a project to be undertaken. These subjective criteria could from the basis of an accompaniment to the 'urban house in paradise' assessment tool, to evaluate the design quality of a project in addition to its performance against the benchmarks proposed in chapter 3.0, refer to volume1.

0.0 Basic Project Information

001 Project tile
002 Location
003 Architect
004 Structural engineer
005 Environmental engineer
006 Quantity surveyor
007 Principal contractor
008 Completion date
009 Form of contract
010 Project abstract
011 Key drawings
012 Slides
013 Photos
014 Video
015 Bibliography: periodicals
016 Bibliography: CARCU library

017 Bibliography: related projects

1.0 Objective Criteria

101 Land: greenfield

102 Land: brownfield

103 Site area

104 Cost: overall project cost (Euro and national currency)

105 land cost (Euro and national currency.m^{-2})

106 cost: area (Euro.m^{-2} and national currency.m^{-2})

107 cost: volumetric (Euro.m^{-3} and national currency.m^{-3})

108 1998 equivalent cost (Euro and national currency)

109 cost per habitant (Euro and national currency)

110 labour rates (final account / number of operatives)

On a country-by-country basis differences of construction cost, arising from, for example, labour costs, could be accepted as an inevitability of building within a specific country. This would, in effect, create a more true reflection of the costs that one would expect to arise if one were to build within that specific country when compared to others.

The IUA publication *Habitation* contains projects from many different countries. The solution utilised to allow comparison between building costs is to list the cost of a project in its national currency, and to provide a table of monetary exchange rates as an appendix. This method will provide an accurate guide at the time of writing, but will be subject to inaccuracy as exchange rates fluctuate. Therefore, the inclusion of an exchange rate table would result in it containing unreliable information, which could lead to inaccurate analysis. Unless an exchange rate table could be regularly updated, there does not appear to be a method of circumventing the issue of exchange rate fluctuations. If exchange rate information were omitted, it would cause the user to seek up to date figures.

Each project being assessed could be analysed by its national currency, to allow more accurate comparisons at a future date but, for the purposes of comparative analysis projects could be compared on the basis of a single currency, the relative Euro costs, which the cost of the project is converted into at the time of entry. The date of conversion would be included, to account for future inflation. As a universal currency the Euro would reduce exchange rate influences between an increasing number of European countries, which may well constitute a significant proportion of the projects being considered.

Once the overall project cost is established, the cost can be analysed in a variety of respects. Euro.m^{-2} would be the standard unit of cost measurement. The IUA criteria analyse cost in slightly more depth, by including figures for land cost, and building cost both per m^2 and per m^3. Land costs could be particularly relevant for urban sites to account for the potential decontamination of brownland that may be required. Volumetric costs will account for ceiling heights and spaces over single storey in height.

The Portsmouth Polytechnic study, *Nine by Ten*, analyses construction costs in greater depth, and includes capital cost figures, 1971 equivalent cost figures, which will allow contemporary costs to be calculated with respect to inflation, cost per square foot, cost per cubic foot, and cost per bed space.

111 Realisation period: design time (months)

112 Realisation period: construction time (months)

113 Procurement strategy

Procurement can be defined as:

> "... a strategy to satisfy the client's development and/or operational needs with respect to the provision of constructed facilities for a discrete life-cycle."[1]

Or, alternatively:

> "... the amalgam of activities undertaken by a client to obtain a building."[2]

The latter definition could also be expressed as, if architecture is the event, procurement can be considered as the effects bringing about that event.

A principle of these definitions is that the choice of procurement strategy will be largely affected by, among other influences, the client's desires. The procurement of a constructed facility is a balance between quality time and cost; each strategy can be located within a Quality-Time-Cost triangle.[3] The particular needs of the client can be acknowledged by distorting the triangle in the direction of emphasis desired. The desired balance between each of the three influences will help determine the procurement strategy most suitable to achieving the desired result. The codification of procurement will commence by determining and defining what influences each heading within the triangle.

Quality (product)	**Time** (programme)	**Cost** (price)
design: concept	design + construction	certainty
detail	life-cycle	land costs
materials	completion at time	design fees
workmanship	completion before time	contract costs
sustainability	certainty	construction
energy		financing costs
performance		value
client satisfaction		political influences
user satisfaction		lifecycle costs
value		management
ease of dismantling		monitoring

The aim is to establish a methodology to analyse the strategy used to procure urban housing projects, and to derive a way in which to asses the quality and value of that strategy in realising the desires of the user and client within the 'constructed facility.' One method in which to do this could be firstly, to determine the initial balance of the client's desires within the Quality-Time-Cost triangle, and then the extent to which the client was satisfied with the project outcome, and therefore determine if the chosen

---

[1] Davidson, Professor Colin H. (ed.). *Procurement - The Way Forward*, London: IF Research Corporation, 1998, p. 79.

[2] Franks, James. *Building Procurement Systems*, London: The Chartered Institute of Building, 1990.

[3] Turner, A. *Building Procurement*, London: Macmillan, 1997, p. 78.

procurement strategy satisfied that balance. If the procurement route failed to achieve the desired outcomes then analysis could be conducted to establish the causes of those failures; this may suggest alternative procurement strategies for that particular arrangement within the QTC triangle.

Evidently, the richer the programmatic diversity of the block, the increased the complexity of tenure, and therefore procurement, becomes. Existing procurement systems could be subject to innovation to administer complex ownership and tenure, in particular in the context of an increasingly mobile workforce.

114 Financing

This criterion will analyse the financing structure used to procure the development. For example, a project may be 100% developer funded, or a percentage of the construction costs may have been paid through a Government grant or lottery funding. Government or State funding may create a link between this and the Political Influences criterion.

115 Density: plot ratio (gross internal area over all floors / site area)

116 Density: dwellings per hectare

117 Density: people per hectare

118 Number of dwellings

119 Dwelling type(s)

The initial analysis of dwelling type will establish housing types within the development, and any mix of types that will have an effect on a project's diversity. Following this is an analysis of the specific numbers of each dwelling type, and variations that exist within each type.

Finally the nature of habitation proposed for the dwellings in analysed. This focuses in particular on the provision for transient habitation, for example separate accommodation for visitors of residents. Or transient habitation may be a part of the changing demographics of the increasingly mobile workforces and population, which present the potential for dwellings for transient inhabitants; in particular if dwellings are a part of related commercial spaces. Extending the notion of the hotel to the autonomous habitation unit.

120 Differentiation of types

Breakdown of the numbers of each dwelling type.

121 Transient accommodation

122 Permanent accommodation

123 Dwelling area: m^2

124 Dwelling volume: m^3

125 Space predicated to mixed functions: m^3 per resident other than dwelling volume

The area of the dwelling will be provided for each dwelling type proposed so that the size of dwellings can be compared between projects for dwellings with equal occupancy figures. Areas will be quantified in m^2, and will be a figure for the total usable floor area, including internal circulation and storage.

A dwelling's volume will be quantified in m^3, and will account for the height of spaces, in particular those over single storey height, for example double height living spaces, which can have a significant influence on the quality of space.

126 Number of storeys

127 Number of thresholds to street: for overall project

128 Number of thresholds to street: for each dwelling unit

The number of thresholds to the street, when viewed in conjunction with the differentiation of numbers of dwellings will be a direct reflection of the dwelling type. For example, for a terraced project, typically the number of terraced dwellings will be the same as the number of thresholds to the street; for an apartment complex the number of dwellings will exceed the number of thresholds to the street.

More importantly, however, the number of entrance thresholds to the street, in addition to the subjective quality of those thresholds, will have a reflection on the quality of a project's integration with the surrounding urban fabric.

129 Number of dwellings served per street threshold

If within a project there is a semi-private space used as a common entrance space to a number of dwellings from one street threshold, the quality of this space can be affected by many factors. This intermediate space was perceived as crucial by the Dutch architect Herman Hertzberger (1932-), who termed it a 'vertical street', and encouraged interaction within this space between the residents who share it. This level of interaction may well be affected by the number of people who use the space; if this number is low there will be insufficient contact between neighbours; if it is too high there will be too many people to create a sense of familiarity between inhabitants and an intimacy within the space.

130 Programme: housing

131 Programme: mixed functions: related to housing

132 Programme: mixed functions: related to city

Hans Kollhoff believes that urban housing should be considered as an integral part of a wider concept of building within the fabric of the city:

> "Housing is a functionalist, anti-urban concept ... Rather than talking about 'housing' or even dwelling,' I would suggest that we consider urban building to be the issue at hand, in all its complexity and contradictions."[4]

In the urban environment, mixed function projects are becoming increasingly common. The promotion of mixed use developments is backed by both the Urban Villages Forum and the Government, who perceive mixed use developments as essential to urban planning approaches.

The provision of functions above those of dwelling can be divided into two categories. Firstly, the provision of facilities for inhabitants beyond the programme of individual dwelling, spaces for a communal dwelling (typical of the majority of Scandinavian urban housing), and therefore still integral with the phenomenon of *block*. Secondly, programmes can be beyond those related to the inhabitants of the block, and be entirely independent of the housing but a part of the wider diversity of the surrounding context. Retail spaces, bars and cafes add to the complexity of the fabric of a project which, according to Kollhoff, is a crucial element in urban building,

"... dwelling, enriched by an urban complexity of functions, becomes habitation."[5]

Innovative housing could provide new relationships between living and working, an already established trend. Flexible spaces for a new typology of urban life; not the immediate classification of living and working spaces, as function *per se*; adaptable spaces, adaptable programmes.

> "... the static notions of forms and function long favoured by architectural discourse need to be replaced by attention to actions that occur inside and around buildings - to the movements of bodies, to activities, to aspirations; in short to the properly social and political dimension of architecture ... Modernism, by which form follows function (or vice versa) needs to be abandoned in favour of promiscuous collisions of programmes and spaces, in which the terms intermingle, combine and implicate one another in the production of new architectural reality."[6]

Alternatively, programmatic diversity could become related through non-typical arrangements. Commercial space could provide habitation spaces for employees within a single block, which would be a reversal of the notion of the live/work unit.

133 Tenure: private sector

134 Tenure: rented

135 Tenure: public sector

136 Tenure: integrated

In order to increase the level of diversity in addition, or as an alternative, to mixed functions, a project can include mixed tenure housing programmes. Within the Greenwich Millennium Village, Hunt Thompson have proposed an integrated weave of private, rented and public sector housing, in a language of form that will render one tenure type indistinguishable from another. More than 170 of the 1377 homes will be rentable, 54 in shared ownership, and 40 available on a flexible tenure basis, which will allow residents to move between ownership, part ownership and renting their homes as their circumstances change.[7] The codification of tenure will establish which forms are included within the project, and then the extent to which these are integrated.

The inclusion of mixed tenure programmes may also be an implication of Government influences on a project, analysed under another criterion.

137 Space use: percentage analysis

A percentage breakdown of spaces, based on function, will be carried out for each dwelling type within a project. This will calculate the proportion of the dwelling's total usable floor area attributed to each function of habitation. A typical breakdown would include:

- living spaces
- sleeping areas
- circulation
- storage
- sanitary facilities

---

[4] Kollhoff, Hans. 'Urban Building Versus Housing,' *Lotus International*, Number 66, p. 101.
[5] Ibid.
[6] Tschumi, Bernard. *Event Cities (Paraxis)*, Cambridge, Massachusetts: The MIT Press, 1996, p. 13.

Within a mixed-use project, a second space usage analysis could be conducted to determine the proportion of the overall floor area attributed to each programme, for example:

- habitation
- administration
- communication
- education
- retail
- service
- production
- storage
- waste

This would provide an indication of emphasis placed on any of the programmes included.

138 Extent of customer-led design: pre-design stages

139 Extent of customer-led design: post-design stages

Inhabitant participation is another paradigm within current housing practice, where participation occurs at both pre- and post-design stages. The Bo 100 complex, Sweden, invited future inhabitants to lead in the design of their individual dwellings, through the construction of 1:20 models. The completed building is a juxtaposition of individual dwellings, with inevitable diversity of architectural form; however, without adaptability these dwellings are user designed for only a single generation of inhabitants.

Hertzberger's IBA block in Berlin presents an alternative process, whereby a proportion of the budget costs were set aside to allow residents, once inhabiting the building, to participate in the construction of communal spaces. Therefore, participation can be subdivided into a pre- and post-design process.

Adaptability can be intrinsic within the process of participation. If participation is conceived as extending beyond the time of initial completion, the user who spatially adapts his or her dwelling in accord with changing demographics, programme or habitation patterns is participating in the architecture of the space.

140 Construction: traditional

141 Construction: system building and prefabrication: open and closed systems

142 Construction: system building and prefabrication: modular or elemental

143 Construction: system building and prefabrication: volumetric

Under the heading of construction, any use of system building, rationalised, standardisation or prefabrication to achieve quality inputs and cost benefits over conventional systems can be analysed. System building can contribute to innovation in prefabrication, adaptability, flexibility and inhabitant participation, the extent of which may largely be dependent upon whether the system is structural or infil.

Standardisation is also a potential paradigm of innovation within the dwelling. Prefabrication can benefit adaptability in the long term, through user participation in the metamorphosis of a dwelling to suit new habitation patterns. Adaptability through an open building system and prefabricated components can be administered by a central management agency, as will be arrangement at the Greenwich Millennium

---

[7] Taylor, David. 'Setting the Agenda for Future Urban Development,' *The Architects Journal*, 26 February 1998.

Village, whereby the evolution of the dwelling will take place within a pre-determined framework.[8] This may also benefit sustainability, through ease of adaptability, and through the increased life cycle of a building through inherent adaptability and ease of maintenance.

144 Political influences: Government incentives

This criterion will determine if, and the extent to which, there was Government or State influence in the inception, finance or procurement of the project.

145 Materials: structure

146 fabric: external walls

147 fabric: roof

148 fabric: windows

149 fabric: floors

150 fabric: stairs

151 fabric: ceilings

152 fabric: separating systems

153 Environmental performance: ground floor (U-value - W.m^{-2}.K^{-1})

154 basement walls (U-value - W.m^{-2}.K^{-1})

155 above ground walls (U-value - W.m^{-2}.K^{-1})

156 separating walls (U-value - W.m^{-2}.K^{-1})

157 roof (U-value - W.m^{-2}.K^{-1})

158 first (and subsequent) floor (U-value - W.m^{-2}.K^{-1})

159 external walls and windows (U-value - W.m^{-2}.K^{-1})

160 air leakage (ac.h^{-1} at 50 Pa)

161 ventilation: natural

162 ventilation: mechanical with heat recovery

163 space and water heating systems

164 space cooling

165 lighting and electrical equipment

166 energy use: total

167 energy use: space heating

168 energy use: water heating

169 energy use: cooking, lighting and appliances

170 energy use: ventilation

171 cost implications

172 construction energy audit – kWh.m^{-2}

173 degree of autonomy

---

[8] Fisher, James. 'Romancing the Home,' *Building Design*, 27 February 1998.

These criteria are liable to be subject to the quality and quantity of information available. Figures are likely to have been calculated for designed thermal performance standards; however, post-completion monitoring or measurement data of actual environmental performance may only be available for a very limited number of projects. Visits to the project would also benefit the environmental assessment of more subjective qualities of the environmental performance. These might include the levels of light within specific task-related spaces and the effects of noise either from the exterior of, or within, the dwelling.

Some elements of analysis within the sphere of environmental performance will overlap with other criteria, for example building fabric materials. Rather than repeating information, the environmental performance criteria will be of a different orientation, focussing on details such as thermal performance and ventilation. Ideally each project would have an element within this criteria that would provide a figure for a total energy audit of the completed building, taking into account factors such as embodied energy arising from material extraction and transport to site. However, such information is specialised, and therefore liable only to be available if environmental performance has been a primary concern of the design team from the project's conception. Mixed-use blocks also have issues relating to sustainability. The 24-hour occupancy patterns of a mixed function block could be exploited in the search for the zero energy dwelling, or the zero energy block. Excess heat produced by commercial spaces during the day could be routed to heat dwellings for their occupants return.

2.0 Subjective Criteria

200 Context:

The influence of context can occur at many levels, and therefore should not be considered only as the effects of the immediate environment on the design of the building. If a project can be considered as divided into two categories of design qualities, standardised - generic qualities that will be consistent regardless of location, and regionalised - the qualities that will be influenced by the country, region, city and site, it is that latter that are all affected by context. Regionalisation will affect many qualities of a dwelling, including relationships between interior and exterior space, relationships between spaces within the dwelling, patterns of habitation, materials, and construction methods. In the national domain, regionalisation can also affect the choice of procurement strategy.

On the immediate scale the valuation of context has several levels of interpretation and definition, and therefore is divided into sub-criteria; these are:

- integration with urban fabric
- relationship to street
- public/private spaces
- relationship with surrounding programmes
- materiality

The issue also arises of whether the valuation of context should be based on the level to which a project integrates with the surrounding urban environment, or the extent to which it successfully articulates the architect's desired level of integration.

201 Integration with urban fabric

This will primarily be articulated by the morphology and massing of the project; the extent to which it relates, or purposefully does not relate, to the surrounding three dimensional urban structure.

202 Relationship to street

Although the quality of a project's relationship to the street will be a part of its integration with the urban fabric, this sub-criterion will focus on the smaller scale synthesis, from the design and articulation of the elevation, to the quality and location of openings and thresholds.

203 Public and private spaces

This criterion will codify the quality of the relationship between the project and its surrounding urban context when mediated by semi-public and semi-private spaces, either open or enclosed, and the quality of those spaces.

204 Relationship with surrounding programmes

Within a mixed-use environment the quality of programmatic integration will be relevant to the valuation of context. As the focus of the thesis is on housing, the focus of this criterion should be on the quality of the integration of the housing element of a mixed-use development with the surrounding programmes.

205 Materiality

Although materiality is a separate criterion, within the influence of context it will be the valuation of the relationship between external material finishes and materials used to construct the surrounding environment. This is not to say that a project which juxtaposes unlike materials will be necessarily attributed with poor value, as the quality of materiality can be based on levels other than visual connection, such as drawing symbolic or theoretical references, which can be as equally contextual as visual likeness.

206 Proportion: scale

207 overall massing

208 principal elevation(s)

Two purposes will be served by this criterion of analysis: firstly it will codify the subjective quality of proportion within the overall design of the block or project; secondly it will determine if any proportion system, for example the Golden Section, the Ken or modular co-ordination, has been used to structure the proportion of the project.[9]

The criterion of proportion has been split into three sub-divisions. Although these divisions may be directly related, they are split in order to allow codification of the quality of proportion in each, as each may be affected by other criteria. The proportionality of the overall block, for instance, will be related to the morphology and integration with the surrounding urban fabric, whilst the proportions of the principal elevation will be related to the quality of the street, and will value the overall harmonies of the elements.

Particularly relevant to housing is the quality of scale: how we perceive the size of the building, element or space relative to other forms. The quality of scale can be divided into two types: generic, the size of a building, element or space relative to other forms in its context, or human, the size of a building, element or space relative to the dimension and proportion of the human body. As the former is related to context, it will be codified in other criteria; it is the latter, the relationship between the human scale and the space, that is of critical importance to the perception of spatiality of a housing project.

209 Hierarchy: spatial

210 programmatic

Hierarchy is subdivided into two classifications: spatial and programmatic. Spatial hierarchy is the degree of importance placed or implied on spaces by their functional, formal or symbolic roles. This will be related to the spatial relationships, zoning and, to some extent privacy, between spaces within the dwelling, and will value the quality of the hierarchies between these spaces. For example, the Portsmouth Polytechnic study divided zoning into two basic methods: by activities (the functions of dwelling), and by family privacy. Programmatic hierarchy will be specifically related to mixed-use projects. This will provide a criterion for the valuation of the relative importance attributed to each programme, for example habitation, retail and commercial, within the project through formal or spatial articulation, and how successfully this articulation reflects the hierarchies established.

211 Adaptability: within dwelling: diurnal

212 Adaptability: within dwelling: episodic

213 Adaptability: within block

In his 1991 Void Space/Hinged Space Housing in Fukuoka, Japan, Steven Holl perceived adaptability occurring on two planes: diurnal and episodic.

> "Diurnal hinging allows an expansion of the living area during the day and a reclamation of bedrooms at night. Episodic hinging reflects the change in a family over time: rooms can be added or subtracted to accommodate grown-up children leaving the family or elderly parents moving in."[10]

The ability of spaces to adapt to the unforeseeable changes in patterns of habitation, speaking both singularly of a particular dwelling, and plurality of the culture of changing habitation patterns and rituals, is increasingly becoming an area of innovation in housing design. Adaptability can extend beyond the individual dwelling, to become an adaptable block, where individual units can be absorbed to create larger dwellings. The latter philosophy of adaptability was notably developed by John Habraken in the 1960s[11], and has recently become a contemporary field of innovation. For example, housing proposed for the Greenwich Millennium Village in London, designed by a team led by the British architectural practice Hunt Thompson Associates in association with the Swedish architect Ralph Erskine, sought to,

> "... bring about a revolution in the concept of procurement and construction of the home in order to facilitate choice and adaptability."[12]

Construction methods focus on prefabrication and open building systems to give the owner/occupier maximum flexibility through a kit of prefabricated parts, which include balconies, conservatories, and kitchen and bathroom units. Whilst a project can be valued on its capacity for adaptability, there is a variety of definitions for the type of adaptability that the dwellings, and project as a whole, may be capable of.

214 Tectonics

---

[9] Ching, Francis D. K. *Architecture: Form, Space And Order*, New York: Van Nostrand Reinhold, 1979.
[10] Holl, Steven. *Intertwining*, New York: Princeton Architectural Press, 1996, p. 18.
[11] Habraken, John N. *Supports: An Alternative To Mass Housing*, London: The Architectural Press, 1972.
[12] Taylor, David. Op. Cit.

Valuing the quality of the disposition and construction of elements of the built form within the project.

215 Spatiality: dwelling/private space

216 Spatiality: semi-private

217 Spatiality: semi-public

218 Spatiality: public

The valuation of spatiality will be an analysis and valuation of the architectonic quality of spaces within the project. This criterion may have to be subdivided, to account for a variety of types of space, for example semi-public and semi-private circulation spaces, and dwelling interiors.

218 Relationship between interior spaces

This criterion will explore the quality of the relationship between spaces within the dwelling; this is subject to several factors of analysis. Spatial relationships within the dwelling can essentially be divided into the following three definitions: firstly, where spaces open from a corridor or hallway; secondly, where spaces open directly from a central open space, typically the living room; and thirdly, the open plan.[13]

In the analysis of the relationship between spaces the Portsmouth Polytechnic study placed an emphasis on the ease of movement from space to space; however the overall quality of spatial relationships will be more complex than this; phenomenological quality will be affected by the flow of space around the dwelling, as well as the flow of its inhabitants.

Adaptability may also reflect on the quality of relationship between spaces, particularly if adaptability is on a diurnal level, through sliding, rotating or folding partitions, which will create the ability to alter the relationship between spaces.

Privacy will be a critical factor, through the manner in which spaces relate to generate, or intentionally minimise, a sense of spatial seclusion. This may be affected by more than just visual qualities; the use of adaptable partitions may result in poor levels of acoustic privacy between spaces.

219 Threshold: doorways

220 Threshold: windows

221 Threshold: balconies

222 Threshold: terraces

In the context of dwelling within urbanity, where the juxtaposition of public and private is intensified, the condition of threshold is one of the most vital conditions, both physically and phenomenologically. Threshold in urban housing is not only the point of access, but can be considered as a dermis, the membrane of maximum tension between interior and exterior, between public and private. It can exist as several levels of definition, from a single event to a sequence of transitions and or spaces.

However, it is not always a matter of public and private activities becoming segregated and distinguished by the threshold. Rather, these two independent conditions can operate separately or in conjunction to describe potentially complex patterns of interaction and relationship. This boundary establishes the conditions under which inside and outside / public and private are able to engage with one another. Balconies and terraces are where private space extends itself into the public realm, and in many instances will be a dwelling's point of most intense integration with that realm. This edge, therefore, is rather paradoxical, since it both separates whilst at the same instance connecting, the two realms it defines. The desirable relationship between public and private, which is mediated by the threshold, is likely to be influenced by the particular culture, or to some extent even city.

223 Articulation of light

The codification of the quality of light within a project will be two-fold. Firstly it will assess the level of light within spaces, with reference to the function of the space. Secondly it will analyse the articulation of light spatially, to create particular perceptual effects. On the articulation of light Steven Holl writes:

> "... early modern architects rationalised the use of light in buildings and called for the hygienic benefits of plate glass. Today, we also understand the importance of the subtleties and psychological differences of a vast range of qualities of light. With as much attention to darkness and to the contrasting secrets of light and dark, we engage in a metaphysics of light."[14]

In particular, light can be used to animate a space, or spaces, on a diurnal cycle, creating a variety of effects as light enters the space during different parts of the day, possibly relating different functions of habitation to the diurnal cycle.

224 Morphology: of mass

224 Morphology: of programme

The quality of a project's morphology, the manipulation of its form, can be considered in relation to mass and programme. The massing of a project will be related to its contextual associations, in particular its integration with the urban fabric and its relationship to the street. The morphology of programme is generated through the manipulation of and relationships between programmes, either related to habitation or diverse from it, within the block.

The codification of the quality of a project's density will, as well as being objective, fall within the subjective division of criteria. The valuation of density will be interwoven with the analysis of context, how the density of the project relates to the surrounding urban fabric, and morphology, or how the massing of the project distributes the density of the project across the site. Therefore, the subjective analysis of density will be conducted under the criteria of context and morphology.

225 Diversity: programme
226 tectonic
227 language
228 context
229 mass

[13] Broadbent, Geoffrey. *Nine By Ten*, Portsmouth: Portsmouth Polytechnic School of Architecture, 1971, p. 70.

The writings of Hans Kollhoff have been cited previously to demonstrate the importance of programmatic diversity as a key factor in urban building. However, the value of diversity in the context of urban building will have a much wider influence over other criteria than just programme. In some respects diversity could be construed as related to, possibly the antithesis of, context. Whereas context could be considered as harmonising the inter-relationship between a project and its surrounding environment, city and region, diversity is the way in which the project articulates attributes of difference of specific qualities or functions. Diversity of form, language and programme as an integral part of urban building is a reflection of the variety and difference, to the extent of non-conformity, that is associated with, encouraged by, and manifested within the urban environment. Therefore the quality of that variety and difference is maintained and encouraged by a project through a balance of context and diversity. The codification of this value of diversity is likely to be through an amalgamation of other criteria, for example: programme, tectonics, language, context, mass. These could be considered individually within each criteria or collectively as a criterion of diversity.

230 Materiality

Whilst the specific materials used within the project have been established through objective analysis, this criteria seeks to codify the subjective nature of the materiality of spaces. This is the way in which materials are articulated and deployed to add to the quality of space, for example to evoke a sense of solidity, fragility or openness; or the intentional use of tactile materials in places where people come into physical, haptic contact with the building.

231 Use of colour

This will codify the quality of the use of colour within the design of a project. The colour of finishes can be manipulated in many ways. For example, colour psychology can be used to create certain emotions within specific spaces; or colour can be used to dematerialise elements or planes, or create focus within a space.

232 Attributes of rurality

233 Attributes of detachment

Currently there is a net migration of population away from urban areas. The attraction of suburban and rural environments is an issue that needs to be addressed by urban housing if this migration is to be reversed. The Greenwich Millennium Village aims to:

> "... attract the suburban market to brownfield sites by attaching 'rural attributes' to urban housing developments."[15]

One example of a rural attribute is distancing, the desire to create a sense of distance between the self and the city. Other attributes of rurality will be considered as a separate paper. As one is able to travel at a wide variety of speeds, the physical distance is less crucial to the sense of separation than time, as it is through time that one perceives the notion of separation from the urban environment. The philosopher Henri Bergson considered that we should speak not in terms of time but duration.[16] The

---

[14] Holl, Steven. Op. Cit., p. 11.

[15] Ben Derbyshire of the architectural practice Hunt Thompson Associates speaking at the Sustainable Urban Communities seminar, held at the Royal College of Physicians, London on 2 April 1998.

[16] Holl, Steven. Op. Cit.

concept of 'lived time' (*durée réelle*) can be related to the process of detaching one's self from urbanity. It is the 'lived time' of the event that creates our sense of separation; distance is a state, a condition, duration and distancing are the process by which it is achieved. This process, the duration of distancing, is a ritual, an act of removing one's self from the urban environment.

Evidently one cannot replicate the physical time and visual scenery, the path to serenity, of the rural separation from the city; therefore this attribute must be synthesised to create the same perception of the duration and process of separation to create a comparable, although seemingly paradoxical, condition of physical juxtaposition and perceptual separation. The issue is also raised of whether the extent of distancing, the extent of duration, will be related to the intensity of the urban environment in which the project is sited.

The codification of the attribute of distance between the urban environment and a project's interiority will be related to the articulation of threshold; however, it will go beyond this single condition, as it is attributing value to the way in which the project articulates the entire ritual of removal, of how one moves from common urban space to the private space of the dwelling. This is likely to be a route involving a succession of transitions and threshold to increase the duration, and therefore the sense, of removal.

The establishment of a sense of separation does not necessitate that the dwellings become insular; it is more a process of establishing a sense of prospect and refuge. Distancing is, therefore, considered as the creation of an *urban threshold*, a ritual the duration of which may encompass several thresholds or spatial transitions. The urban threshold of a project is the articulation of the route between the urban exterior and the dwelling interior. The criterion of distance is, therefore, related to the physical, chrono-, and psychological detachment of a project from the urban environment.

233 Attributes of propinquity

This is a reflection of qualities arising from propinquity within the design, attributes of closeness and proximity in the project, for example between individual dwellings.

234 Client opinion

235 Tenant and occupier opinion

236 Use of smart technologies

237 Harmony of built form

The harmony or counterpoint of the distribution of mass across the project.

238 Harmony of colour

The harmony or counterpoint of the distribution of colour across the project.

Annexe 5

Prioritising the Criteria for the Matrix

Annexe 5.0 Prioritising the Criteria for the Matrix

This annexe contains the analysis used to prioritise the criteria of the matrix against the relative contribution made by each to four parameters of environmental sustainability. These parameters are contribution to the reduction of greenhouse gas emissions, contribution to the reduction in pollution, contribution to the reduction of natural resource consumption and contribution to the reduction of ozone depleting emissions.

For each of the criteria the evaluation is considered in terms of a common unit. For example, in the case of the contribution to the reduction of greenhouse gas emissions the common unit is kgCO_2 per unit floor area per annum. CO_2 is selected because it is the principal gas that causes the anthropocentric greenhouse effect. Therefore if a criterion reduces other emissions, these are converted into the equivalent emissions of CO_2. If the emission is embodied within the dwelling, this value is divided by the design life span of the dwelling. The reduction in emission of pollution is assessed in terms of the reduction in grammes per annum. The reduction in natural resource consumption is measured in terms of the reduction in per unit volume, or per unit area for land. Like CO_2, the evaluation of the contribution to reducing ozone depleting emissions is converted into the equivalent emission of on of the common ozone depleting gases, volatile organic compounds, or VOCs.

5.1 Prioritising – Contribution to the Reduction of the Greenhouse Effect

In order to prioritise the benchmarks in terms of their contribution to the reduction of greenhouse gas emissions, each will be converted into a value of the equivalent reduction in carbon dioxide emissions (the most significant greenhouse gas), which would be achieved by moving from the typical standard of housing to the 'urban house in paradise' benchmark. The most significant benchmark will, therefore, be the one that provides the greatest reduction in CO_2 emissions over a given period, such as one year. The embodied emissions will be divided by the design life span of the dwelling, to give an annual equivalent emissions that can be compared to annual emissions such as the energy consumed during inhabitation. Therefore the emissions will be quantified in terms of $kgCO_2.a^{-1}$ for each of the criteria.

The following presents how the emission per annum will be determined for each criterion, where applicable.

5.1.1 CO_2 Emissions: on site construction processes

The benchmark analysis provided values of the level of CO_2 emission that will occur as a result of the energy consumed during the on site construction of the typical dwelling and the 'urban house in paradise.' These are:

Typical dwelling	$= 54\ kgCO_2.m^{-2}$
'urban house in paradise'	$= 27\ kgCO_2.m^{-2}$

From the Space Standards analysis, the areas of these two dwellings for a mean occupancy level of 2.4 people per dwelling, derived from census data, has been determined as 48.5 m^2 and 59.8 m^2 respectively. Therefore, the total value of emissions will be 2,619 $kgCO_2$ for the 'typical' dwelling, and 1,614.6 $kgCO_2$ for the 'urban house in paradise.' To determine a value of the emission per annum, each of these values will be divided by the respective design life span of the dwelling, as determined by the Lifecycle benchmark. These create levels of emission of 43.7 $kgCO_2.a^{-1}$ and 13.5 $kgCO_2.a^{-1}$. Therefore, the overall reduction that would be created by adopting the benchmark of the 'urban house in paradise' would be:

$$= \mathbf{30.2\ kgCO_2.a^{-1}}$$

5.1.2 CO_2 Emissions: Inhabitation

From the benchmark analysis, the values of CO_2 emission from the energy consumption by heating, lighting and appliances during the inhabitation of the typical speculative built dwelling and the 'urban house in paradise' are 50.2 $kgCO_2.m^{-2}.a^{-1}$ and 10.7 $kgCO_2.m^{-2}.a^{-1}$ respectively. The effects on CO_2 emissions of the benchmarks for Green Space and Water Consumption: Inhabitation are considered as individual criteria to determine their respective significance; to include them here would double count their contribution to the reduction of greenhouse gas emissions. As the 'urban house in paradise' is a larger dwelling, it will have a higher CO_2 emission than a typical speculative built dwelling for the same number of occupants. From the Space Standards research, at an average occupancy of 2.4 people, the typical speculative built dwelling will be 48.5 m^2; the area of the 'urban house in paradise' will be 59.8 m^2 for the same number of occupants.

Therefore:	Typical spec built dwelling	= 48.5 x 50.2	= 2,434.5 $kgCO_2.a^{-1}$
	'urban house in paradise'	= 59.8 x 10.7	= 639.9 $kgCO_2.a^{-1}$

Therefore, for a dwelling based on the average occupancy figures of households in the United Kingdom, moving from the standard of the typical dwelling to that of the 'urban house in paradise' will create a reduction in carbon dioxide emission of:

2,434.5 – 639.9 = **1,794.8 $kgCO_2.a^{-1}$**

5.1.3 Carbon Intensity

From the benchmark of Energy Consumption: Inhabitation, the energy consumption for space and water heating for the 'urban house in paradise' can be determined as 12 $kWhm^{-2}.a^{-1}$. Using the mean occupancy level of 2.4 people per dwelling, taken from census data, the Space Standards: Area benchmark can be used to determine a notional area of the 'urban house in paradise' of 59.8 m^2. Therefore, the energy consumption of this dwelling can be determined as 12 x 59.8 = 717.6 kWh.

The 'typical' dwelling's benchmark of carbon intensity is 0.28 $kg.kWh^{-1}$, and the value for the 'urban house in paradise' is 0.24 $kg.kWh^{-1}$ this gives a difference in the performance of 0.04 $kg.kWh^{-1}$. Therefore, the reduction achieved by moving between these two benchmarks would be:

0.04 x 717.6 = 28.7 $kgC.a^{-1}$

As 1 kgC is the equivalent of 3.67 $kgCO_2$, then the reduction, in terms of CO_2 would be:

28.7 x 3.67 = **105.3 $kgCO_2.a^{-1}$**

5.1.4 Construction Period

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the greenhouse effect.

5.1.5 Contextual Significance of the Site

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the greenhouse effect.

5.1.6 Deconstruction and Demolition: Recycling of Materials

The aim of the benchmark of this criterion is to reduce the quantity of material that is sent to disposal through landfill by increasing the proportion that is used for high level recycling.

One of the by-products of landfill waste is gas emission. The principal landfill gases are methane (CH_4) and carbon dioxide, both of which contribute to the greenhouse effect. These are produced through the decomposition of the organic putrescible component of the waste. Although the relative proportions of the gases emitted from landfill changes over time, on average it can be determined as 63.8 percent CH_4, 33.6 percent CO_2 and 2.6 percent trace gases.[1] The high proportion of CH_4 exacerbates the contribution to the greenhouse effect, as it much more 'effective' as a greenhouse gas than CO_2.

The benchmark analysis determined that on average 66 percent of demolition waste goes to landfill. However, of that figure it is only the organic putrescible waste that will decompose and produce emissions; the inert content will remain in a steady condition and produce no emissions.

The quantities of materials arising from the demolition of a dwelling will be based upon those determined under the Contribution to the Reduction of Natural Resources criterion, detailed under the Deconstruction and Demolition criterion, of the quantity of primary bulk materials that might be used to construct an 'urban house in paradise'. Of these, the only material that will be subject to decomposition will be the timber content, which was determined at

[1] Department of the Environment. *Waste Management – Landfilling Wastes*, London: HMSO, 1986.

2,285 kg. It is typically the masonry content of demolition waste that is currently reused or recycled; estimates made by the Building Research Establishment suggest that 80 percent of timber is sent to landfill, whilst 15 percent is reclaimed.[2] Of the timber that goes to landfill, it has been estimated that half decomposes whilst the rest remains inert.[3] Thus, the 85 percent reduction benchmarked for the 'urban house in paradise' would equate to a quantitative value of:

2285 x 0.85 = 1942.3 kg

Accounting for the existing value of timber the is reclaimed:

2285 x 0.15 = 342.8 kg

Therefore, the reduction in the quantity of timber that is sent to landfill is:

1942.5 – 342.8 = 1599.6 kg

Spread across the life span of the dwelling, this would equate to an equivalent annual reduction of:

1599.6 / 120 = 13.3 kg.a_1

For each kilogram of waste disposed of by landfill, 0.15 $kgCH_4$ and 0.39 $kgCO_2$ will be produced.[4] Therefore, the emissions of CH_4 and CO_2 as a result of the waste disposed of per annum will be:

(13.3 / 2) x 0.15 = 1.00 $kgCH_4$

(13.3 / 2) x 0.39 = 2.60 kg CO_2

From Rodhe, each kilogram of CH_4 emitted into the atmosphere has the equivalent effect of 70 kilograms of CO_2.[5] Therefore, the total equivalent CO_2 emission will be:

(1.00 x 70) + 2.60 = 73.1 $kgCO_2$

---

[2] Howard, Nigel, Suzy Edwards and Jane Anderson. *BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings*. London: Construction Research Communications Limited, 1999.

[3] Royal Commission for the Environment. *Seventeenth Report*, London: HMSO, 1993.

[4] Tchobanoglous, George, Hilary Theisen and Rolf Eliassen. *Solid Wastes – Engineering Principles and Management Issues*, London: McGraw-Hill, 1977.

[5] Rodhe, Henning. 'A Comparison of the Contribution of Various Gases to the Greenhouse Effect,' *Science*, 8 June 1990.

However, it must be remembered that this value represents the total quantity of gas that is produced by the waste over the total period of decomposition of at least 50 years, therefore this will translate to an annual emission of:

73.1 / 50 = **1.5 $kgCO_2.a^{-1}$**

5.1.7 Design life span

Whilst some of the benchmarks, such as Energy Consumption: Inhabitation, are quantified in units per annum, increasing the lifespan of the dwelling will have an impact on a number of the criteria. For example, in a dwelling with a 'typical' design life span, the embodied energy will be used to create a dwelling that is deigned to last for 60 years; whereas, if the dwelling were to last 120 years, this would be a more efficient use of the energy consumed in creating it. This will also be the case for wastes created during its construction. The contribution of the design life span benchmark to the reduction of greenhouse gases is the cumulative effect of increasing the design life span of the dwelling by 60 years. To determine this, each criterion, where applicable, was taken individually and then the contributions all summed. A more detailed description of the methodology used to determine the values is given under each criterion elsewhere in the parameter.

CO_2 Emissions: Construction and Deconstruction

The value of CO_2 emissions created by these processes will be included within the overall calculation of the Ecological Weight: Embodied Energy and Embodied CO_2 criteria, and therefore should not be included here so that its effect is not double counted when the cumulative total is determined.

Deconstruction and Demolition: Recycling of Materials

The benchmark for the recycling or reuse of deconstruction and demolition material is 85 percent. It is the timber content of this waste that will decompose to produce greenhouse gas emissions, therefore it is that component that will be considered. From the benchmark up to 15 percent of the total timber content may be sent to landfill, which, from the model analysis for this criterion under the parameter of Contribution to the Reduction of Natural Resource Consumption, is 2,285 kg. Therefore, the potential landfill value is 342.8 kg.

342.8 / 60 = 5.71 $kg.a^{-1}$

342.8 / 120 = 2.86 $kg.a^{-1}$

∴ effect of life span = 2.85 $kg.a^{-1}$

For each kilogram of waste disposed of by landfill, 0.15 $kgCH_4$ and 0.39 $kgCO_2$ will be produced. Therefore, the emissions of CH_4 and CO_2 as a result of the waste disposed of per annum will be:

(2.85 / 2) x 0.15 = 0.21 $kgCH_4$

(2.85 / 2) x 0.39 = 0.55 kg CO_2

From Rodhe, each kilogram of CH_4 emitted into the atmosphere has the equivalent effect of 70 kilograms of CO_2. Therefore, the total equivalent CO_2 emission will be:

(0.21 x 70) + 0.55 = 15.3 $kgCO_2$

However, it must be remembered that this value represents the total quantity of gas that is produced by the waste over the total period of decomposition of at least 50 years, therefore this will translate to an annual emission of:

15.3 / 50 = 0.31 $kgCO_2.a^{-1}$

Ecological Weight: Embodied Energy

In determining the cumulative effect of the design life span benchmark, this criterion is concerned with the emissions of greenhouse gases other than CO_2, so that when the values for all the criteria are added to determine an overall value, the embodied CO_2 emission will not be double counted. The embodied CO_2 emission is determined below.

On the basis of the average occupancy level and the Space Standards: Area benchmark, the embodied energy for the 'urban house in paradise' is 59.8 x 250 = 14,950 kWh. The effect of the life span benchmark is:

14,950 / 60 = 249.2 $kWh.a^{-1}$

14,950 / 120 = 124.6 $kWh.a^{-1}$

∴ effect of life span = 124.6 $kWh.a^{-1}$

Therefore, the greenhouse gas emissions associated with this reduction are:

Electricity:	41.5 x 1.350	= 56.1 $gCH_4.a^{-1}$
	41.5 x 0.02997	= 1.24 $gN_2O.a^{-1}$
Gas:	41.5 x 0.448	= 18.6 $gCH_4.a^{-1}$
	41.5 x 0.00039	= 0.016 $gN_2O.a^{-1}$
Petroleum	41.5 x 0.162	= 6.73 $gCH_4.a^{-1}$
	41.5 x 0.12378	= 5.14 $gN_2O.a^{-1}$

$= 81.4\ gCH_4.a^{-1}$

$= 6.40\ gN_2O.a^{-1}$

As gram for gram methane is 70 times as effective as CO_2, in terms of its contribution to the greenhouse effect, the emissions of CH_4 arising will be the equivalent of 81.4 x 70 = 5.70 $kgCO_2$. As nitrous oxide is 200 times as effective, gram for gram, as CO_2 in terms of its contribution to the greenhouse effect, the emissions of N_2O arising be the equivalent of 6.40 x 200 = 1.28 $kgCO_2$.

Therefore, in total the effect of the design life span benchmark on the additional embodied emissions to that of CO_2, determined next, is:

$= 6.98\ kgCO_2.a^{-1}$

Ecological Weight: Embodied CO_2 Emission

The value of embodied CO_2 emissions for the 'urban house in paradise' was determined under that criterion, below, as 5,382 $kgCO_2$. This value spread across a 60 year life span would be 89.7 $kgCO_2.a^{-1}$; spread across a 120 year life span, this would be 44.9 $kgCO_2.a^{-1}$. Therefore, the reduction in emissions achieved by the increased design life span of the dwelling is:

89.7 – 44.9 $= 44.8\ kgCO_2.a^{-1}$

Energy Consumption: Construction Processes

The emission of greenhouse gases created by these processes will be included within the overall calculation of the Ecological Weight: Embodied Energy criterion, and therefore should not be included here so that its effect is not double counted when the cumulative total is determined.

Recycling of Construction Waste

The quantity of organic construction waste that will arise from the benchmarked standard will be 57.1 kg; refer to Recycling of Construction Waste criterion, below, for the derivation of this value. The effect of the design life span benchmark will be:

57.1 / 60	$= 0.95\ kg.a^{-1}$
57.1 / 120	$= 0.48\ kg.a^{-1}$
∴ effect of life span	$= 0.47\ kg.a^{-1}$

The quantity of timber that will decompose will be 50 percent of the total sent to landfill; the rest will remain inert. For each kilogram of waste disposed of by landfill, 0.15 $kgCH_4$ and 0.39 $kgCO_2$ will be produced.[6] Therefore, the emissions of CH_4 and CO_2 as a result of the waste disposed of per annum is:

$$(0.47 / 2) \times 0.15 = 0.036 \text{ kgCH}_4$$

$$(0.47 / 2) \times 0.39 = 0.092 \text{ kg CO}_2$$

From Rodhe, each kilogram of CH_4 emitted into the atmosphere has the equivalent effect of 70 kilograms of CO_2. Therefore, the total equivalent CO_2 emission will be:

$$(0.036 \times 70) + 0.092 = 2.61 \text{ kgCO}_2$$

However, it must be remembered that this value represents the total quantity of gas that is produced by the waste over the total period of decomposition of at least 50 years, therefore this will translate to an annual emission of:

$$2.61 / 50 = 0.05 \text{ kgCO}_2.a^{-1}$$

Space Standards

Although during the calculation of the effect of the Space Standards: Area and Volume benchmarks on the emission of greenhouse gases, the life span of the dwelling was used, it will not be a part of the cumulative effect of the design life span benchmark. The Ecological Weight: Embodied Energy and Embodied CO_2 criteria have both already taken account of the consequential impact on emissions incurred through the increase in area created by the Space Standards benchmark.

Thermal Performance

The impact of increasing the level of thermal performance of the dwelling's fabric will be accounted for within the Ecological Weight: Embodied Energy and Embodied CO_2 criteria, and will not be assessed here so as not to double count when calculating the cumulative effect.

---

[6] Tchobanoglous, George, Hilary Theisen and Rolf Eliassen. *Solid Wastes – Engineering Principles and Management Issues*, London: McGraw-Hill, 1977.

Therefore, in total the reduction in the emission of gases that contribute to the greenhouse effect achieved through increasing the design life span of the dwelling to the benchmark of the 'urban house in paradise' will be:

$$0.31 + 6.98 + 44.8 + 0.05 = \mathbf{52.1\ kgCO_2.a^{-1}}$$

5.1.7 Density: Quantitative

The typical value of residential density determined by the analysis of the benchmark values is 100 $people.ha^{-1}$; for the 'urban house in paradise' the minimum value of residential density has been determined as 370 $people.ha^{-1}$.

Therefore, the base density for the 'urban house in paradise' is 3.7 times higher than that of the typical dwelling; thus it will, in effect, occupy 3.7 times less footprint space than the typical dwelling. Using the typical occupancy level of dwellings of 2.4 people, for the purposes of a relative comparison, 370 $people.ha^{-1}$ equates to 154 $dwellings.ha^{-1}$. At this density, in effect, 64 m^2 of land will be attributable to each dwelling; the same number of dwellings at the typical residential density would occupy 3.7 times the area. Therefore, the land saved by moving from the benchmark of the typical residential density to that of the 'urban house in paradise' can be equated to 176 m^2.

Ecological footprinting is a methodology used to determine environmental impact. It is quantified in terms of the land area required to provide the needs and resources of, and to assimilate the wastes generated by, human consumption. In terms of fossil fuels, there are approaches to converting fossil energy consumption into a corresponding land area. The most frequently used method estimates the land area required to sequester the CO_2 emitted from burning fossil fuels. The argument is based on the approach that fossil carbon (in the form of CO_2) cannot be allowed to accumulate in the atmosphere due to the potential effects of climate change.

Research into the ecological footprint of fossil fuels has determined that one hectare of greenspace can sequester the CO_2 emission generated annually by the consumption of 100 gigajoules of fossil fuel. This value has been derived from the fact that the most effective assimilators of CO_2 in terms of greenspace, which are forests, accumulate 1.8 tonnes of carbon per hectare.[7] This value can be used to determine the best case scenario for the

[7] Wackernagel, M. and W. Rees. *Our Ecological Footprint*, Oxford: New Society Publishers, 1996.

potential level of annual CO_2 absorption by the greenspace benchmarked to be provided for each dwelling.

On the basis of the area of land saved by achieving the benchmarked density of the 'urban house in paradise', a value can be proposed for the level of CO_2 that could potentially be sequestered by that area of land. Of course this value will be a theoretical maximum, for it will be based on the assumption that the land saved will be green space, whereas in an urban context the site could be already built upon, or may not be green space. The criterion of Ecological Value of the Site will be used to determine the contribution achieved through developing upon brownfield as opposed to greenfield land.

1.8 tonnes of carbon per hectare is the equivalent of 0.66 $kgCO_2.m^{-2}$. If the land area saved through the density benchmark is 160 m^2 per dwelling, this will equate to a potential reduction in the net CO_2 level in the atmosphere of:

$$176 \times 0.66 \quad = \mathbf{116.2\ kgCO_2.a^{-1}}$$

However, as established above, this value must be treated with a degree of caution, as the value is, in reality, likely to be less than this.

5.1.8 Density: Qualitative

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the greenhouse effect.

5.1.9 Diversity: Programme

In terms of its benchmark value, this criterion is considered to have no direct consequential effect on the reduction of the greenhouse effect. An indirect effect that creating a mixed-use project would be the reduction in emissions arising from transport, through providing facilities within walking distance. However, it is beyond the scope of this study to undertake an analysis of the magnitude of such reduction in terms of the programmatic diversity benchmark proposed.

5.1.10 Domestic Waste

The current national average value for domestic waste recycling is 6.5 percent. Of the remaining 93.5 percent, 85 percent is disposed of through landfill. The remainder is incinerated, 3.5 percent with heat recovery and 5 percent without.[8] The organic materials within domestic waste, for example food, garden waste, paper and cloth, typically account for 60 percent of the total mass, refer to benchmark analysis of Domestic Waste Recycling, Annexe 3.11.

From the benchmark analysis, the typical dwelling produces 8.7 kg per person per week of domestic waste, or 452.4 $kg.p^{-1}.a^{-1}$. All of this will assumed to be disposed of by landfill. In the 'urban house in paradise' the refuse that is disposed of as opposed to recycled amounts to 2.4 kg per person per week, or 124.8 $kg.p^{-1}.a^{-1}$. For each kilogram of waste disposed of by landfill, 0.15 $kgCH_4$ and 0.39 $kgCO_2$ will be produced. Therefore, the emissions of CH_4 and CO_2 as a result of the waste disposed of per person per annum will be:

typical dwelling = 67.8 $kgCH_4$ and 178.5 kg CO_2
'urban house in paradise' = 18.7 $kgCH_4$ and 49.2 kg CO_2

Therefore, the reduction is 49.1 $kgCH_4$ and 129.3 kg CO_2 per person or, assuming average dwelling occupancy of 2.4 people, 117.8 $kgCH_4$ and 310.3 $kgCO_2$ per household. From Rodhe, each kilogram of CH_4 emitted into the atmosphere has the equivalent effect of 70 kilograms of CO_2. Therefore, if the reduction of waste to landfill creates a reduction of 117.8 $kgCH_4$ being emitted into the atmosphere, this will be the equivalent of a reduction of 8,246 $kgCO_2$. Added to the CO_2 that is emitted as a result of the decomposition of the waste, this equates to a total reduction of 8,556.3 $kgCO_2$.

However, it must be remembered that this is the quantity of gas that is produced by the waste over the total period of decomposition. This is a period of 50 years or more. Also, this figure represents the theoretical maximum emission through the chemical process of complete decomposition of the waste. In reality this is likely to be less, due to there being insufficient water and oxygen available for decomposition, and some waste being unavailable for decomposition, such as any sealed within plastic bags. This level, therefore, presents a worst case scenario.

Whilst there will also be emissions arising from the processing of the materials sent to be recycled into their recycled form, this is discounted. These are considered to be equivalent to the emissions that would be created by the processing of the virgin materials that would

[8] Department of the Environment. 'Authoritative Municipal Waste Statistics Released', press release, 9 June 1997.

have been used had the recycled ones not been available. Furthermore, in research suggests that the quantity of energy consumed in refining recycled materials is less than that consumed in processing virgin ones.

Therefore, the total equivalent reduction of CO_2 emission per annum by moving from the level of waste disposed to landfill in the typical dwelling, to the level of the 'urban house in paradise' will be,

$$= \mathbf{171.1\ kgCO_2.a^{-1}}$$

5.1.11 Ecological Significance of the Site

Under the Density: Qualitative criterion, it was determined that the mean occupancy level of 2.4 people per dwelling, 64 m^2 of land will be attributable to each dwelling. The Ecological Significance of the Site benchmark states that 100 percent of the land used by the 'urban house in paradise' will be brownfield as opposed to greenfield. As green space contributes to a reduction in the net levels of CO_2 in the atmosphere through the process of photosynthesis, this reduction in the consumption of greenfield land by housing development can be translated into a reduction of CO_2. This will be a theoretical maximum value, as the levels of CO_2 sequestered are based on the most efficient types of greenspace, namely forests; agricultural land will not be capable of providing the same levels of net reduction.

The level of sequestering has been determined as 1.8 tonnes of carbon per hectare per annum. This can be translated as 0.66 $kgCO_2.m^{-2}.a^{-1}$. Therefore a green space land reduction of 64 m^2 will equate to a potential CO_2 reduction of:

$$0.66 \times 64 \qquad = \mathbf{42.2\ kgCO_2.a^{-1}}$$

5.1.12 Ecological Weight: Embodied Energy

The effect of this benchmark on CO_2 emissions will be considered under the Ecological Weight: CO_2 Emissions criterion. Its effect will be:

$$= 246.2\ kgCO_2.a^{-1}$$

However, there will also be a reduction in the emissions of other gases are also produced through the combustion of fossil fuels. The significant of these in terms of contribution to global warming are methane (CH_4) and nitrous oxide (N_2O). The other emissions will be considered under the parameters of Pollution and Contribution to the Depletion of the Ozone

Layer. For the purposes of comparative analysis, from the Ecological Weight: Embodied Energy and Space Standards: Area benchmarks, it can be determined that the embodied energy for the 'typical' dwelling is:

1,000 x 48.5 = 48,500 kWh

Also, that the embodied energy for the 'urban house in paradise' is;

250 x 59.8 = 14,950 kWh

Therefore, the reduction in embodied energy that will be achieved through the benchmark reduction is:

48,500 – 14,950 = 33,550 kWh

Across the design life span of the dwelling, this is the equivalent annual reduction of:

33,500 / 120 = 279.2 $kWh.a^{-1}$

The Building Research Establishment's *Methodology for Environmental Profiles* determines the emissions associated with fuel consumption from the NETCEN National Atmospheric Emissions Inventory, based on 1996 figures, which are the most recent available.[9] These figures also take into account the upstream emissions arising from the extraction, refining, supply, and transmission as well as the energy consumed in extraction, refining and supply. They are summarised in the table below.

Gas Emitted	Emission factors of fossil fuels ($g.kWh^{-1}$)		
	Gas	Oil	Coal
CH_4	0.403	0.076	0.940
N_2O	0.00036	0.00212	0.02689

Emission of methane and nitrous oxide by different fuel types

In terms of generating electricity, accounting for the inefficiencies of power stations and transmission means that per kWh of delivered energy the emissions of CH_4 and N_2O is summarised in the following table.

[9] Howard, Nigel, Suzy Edwards and Jane Anderson. Op. Cit.

Gas Emitted	Emission factors ($g.kWh^{-1}$ delivered electricity)		
	Gas	Oil	Coal
CH_4	1.008	0.190	3.133
N_2O	0.00090	0.00530	0.08963

Emission of methane and nitrous oxide by different fuel types by delivered electricity

On the basis of the fossil fuel mix used to generate electricity, derived from the Digest of United Kingdom Energy Statistics 1998[10], of 33 percent coal, 31 percent gas, 26 percent nuclear and 2 percent oil, it can be determined that to generate one kWh of electricity will create the following emissions form each fuel type:

Gas Emitted	Emission factors on the basis of generation mix ($g.kWh^{-1}$)			
	Gas	Oil	Coal	**TOTAL**
CH_4	0.312	0.004	1.034	1.350
N_2O	0.00028	0.00011	0.02958	0.02997

Emission of methane and nitrous oxide on the basis of generation mix

The values for natural gas and petroleum consumption will account for the typical relative efficiency of appliances consuming those sources.[11]

It is assumed that a 1:1:1 ratio for the mixture of electricity:gas:petroleum fuel types is used during the period of embodied energy consumption, this gives a consumption per fuel type of 93.1 $kWh.a^{-1}$. It may be possible to determine a more accurate value for specific materials dependent upon the balance of fuels types used. This would require a detailed profile to be established for each material. Such work has been commenced by the Building Research Establishment, in terms of studying materials within factory production processes, which is held on a confidential database and therefore access to this information was not

[10] Department of Trade and Industry. *Digest of United Kingdom Energy Statistics 1998*, London: HMSO, 1998.
[11] Thomas, Randall (ed). *Environmental Design*, London: E & F N Spon, 1996.

possible.[12] Hence the calculation is based upon a 1:1:1 ratio. Therefore, the greenhouse gas emissions associated with each fuel are:

Electricity:	93.1 x 1.350	= 125.6 $gCH_4.a^{-1}$
	93.1 x 0.02997	= 2.79 $gN_2O.a^{-1}$
Gas:	93.1 x 0.448	= 41.7 $gCH_4.a^{-1}$
	93.1 x 0.00039	= 0.04 $gN_2O.a^{-1}$
Petroleum	93.1 x 0.162	= 15.1 $gCH_4.a^{-1}$
	93.1 x 0.12378	= 11.5 $gN_2O.a^{-1}$
		= 182.4 $gCH_4.a^{-1}$
		= 14.3 $gN_2O.a^{-1}$

As methane is 70 times as effective, gram for gram, as CO_2 in terms of its contribution to the greenhouse effect, the emissions of CH_4 arising from the embodied energy will be the equivalent of 182.4 x 70 = 12.8 $kgCO_2$. As nitrous oxide is 200 times as effective, gram for gram, as CO_2 in terms of its contribution to the greenhouse effect, the emissions of N_2O arising from embodied energy will be the equivalent of 14.3 x 200 = 2.9 $kgCO_2$.

Therefore, the total reduction in the contribution to the greenhouse effect made by achieving the benchmark of the 'urban house in paradise' will be:

246.2 + 12.8 + 2.9 **= 261.9 $kgCO_2.a^{-1}$**

5.1.13 Ecological Weight: Embodied CO_2 Emission

From the benchmark analysis there are values of the consequent CO_2 emissions from the embodied energy in materials for both the typical dwelling and the 'urban house in paradise'. These are 360 $kgCO_2.m^{-2}$ and 90 $kgCO_2.m^{-2}$ respectively. From the Space Standards research, at an average occupancy of 2.4 people, the typical speculative built dwelling will be 48.5 m^2; the area of the 'urban house in paradise' will be 59.8 m^2 for the same number of occupants.

Therefore:	Typical spec built dwelling	= 48.5 x 360	= 17,460 $kgCO_2$
	'urban house in paradise'	= 59.8 x 90	= 5,382 $kgCO_2$

---

[12] Personal communication: Jane Anderson, Consultant, Centre for Sustainable Construction, Building Research Establishment, 13 January 2000.

To convert this into the emission over the period of one year, this value will be divided by the design life span for each dwelling, which is taken from the Definition of Lifecycle criterion:

Typical spec built dwelling	= 17,460 / 60	= 291 $kgCO_2.a^{-2}$
'urban house in paradise'	= 5,382 / 120	= 44.9 $kgCO_2.a^{-2}$

Therefore, the reduction in carbon dioxide emission that would be achieved by moving from the typical speculative standard to the benchmark of the 'urban house in paradise' would be:

291 – 44.9 **= 246.2 $kgCO_2.a^{-1}$**

5.1.14 Energy Consumption: Construction Processes

Under the criterion of CO_2 Emissions: construction and deconstruction it was determined that the reduction in CO_2 emissions from construction processes would be 30.2 $kgCO_2.a^{-1}$. As for the other criteria that benchmark a reduction in the consumption of fossil fuel, there will also be a reduction in other gases that contribute to global warming.

The reduction in energy consumption during on site construction can be determined from the benchmark analysis. From the mean occupancy value, Space Standards: Area and Energy Consumption: Construction Processes benchmarks, the reduction in energy consumption can be determined as:

'typical':	150 x 48.5	= 7,275 kWh
'urban house in paradise'	75 x 59.8	= 4,485 kWh
∴ reduction =	7,275 – 4,485	= 2,790 kWh

Across the life span of the dwelling, this will equate to an annual equivalent reduction of:

2,790 / 120 = 23.3 $kWh.a^{-1}$

In terms of fuel mix, gas will not be used as much for a fuel source during on site construction, and therefore the ratio has been proposed as 4.5:4.5:1 for electricity:petroleum:gas.

Therefore, the reduction in the emissions of methane and nitrous oxide emissions by fuel type will be:

Electricity:	10.5 x 1.350	= 14.18 $gCH_4.a^{-1}$
	10.5 x 0.02997	= 0.31 $gN_2O.a^{-1}$
Gas:	2.3 x 0.448	= 1.03 $gCH_4.a^{-1}$

	2.3 x 0.00039	= 0.001 $gN_2O.a^{-1}$
Petroleum	10.5 x 0.162	= 1.70 $gCH_4.a^{-1}$
	10.5 x 0.12378	= 1.30 $gN_2O.a^{-1}$

= 16.91 $gCH_4.a^{-1}$

= 1.61 $gN_2O.a^{-1}$

As methane is 70 times as effective, gram for gram, as CO_2 in terms of its contribution to the greenhouse effect, the emissions of CH_4 arising from the embodied energy will be the equivalent of 16.91 x 70 = 1.2 $kgCO_2$. As nitrous oxide is 200 times as effective, gramme for gramme, as CO_2 in terms of its contribution to the greenhouse effect, the emissions of N_2O arising from embodied energy will be the equivalent of 1.61 x 200 = 0.3 $kgCO_2$.

Therefore, in total the reduction in contribution to the emission of greenhouse gases, in equivalent terms, will be:

30.2 + 1.2 + 0.3 **= 31.7 $kgCO_2.a^{-1}$**

5.1.15 Energy Consumption: Inhabitation

Whilst the emission of CO_2 that arises as a consequence of the burning of fossil fuels to fulfil the energy demands of the dwelling are determined under CO_2 Emissions: Inhabitation, other gases are also produced through the combustion of fossil fuels, albeit to a lesser extent. The only significant of these in terms of a contribution to global warming are methane (CH_4) and nitrous oxide (N_2O). The others will be considered under the parameters of Pollution and Contribution to the Depletion of the Ozone Layer.

The values for the emissions per kWh for each fossil fuel type, derived under the Ecological Weight: Embodied Energy in Materials, can be used here to determine the emissions from the energy consumed during the period of inhabitation. The electricity saving by moving from the energy consumption of the 'typical' dwelling to that of the 'urban house in paradise' would be:

Typical spec built dwelling	= 48.5 x 38	= 1,843
'urban house in paradise'	= 59.8 x 10	= 598
	∴ reduction	= 1,245 $kWh.a^{-1}$ electricity

The reduction in the emissions of CH_4 and N_2O will, therefore, be:

1,245 x 1.350 = 1,680.8 $gCH_4.a^{-1}$

1,245 x 0.02997 = 368.3 $gN_2O.a^{-1}$

Therefore, the reduction in CH_4 and N_2O emission as a result of the reduction in electricity consumption by achieving the benchmark of the 'urban house in paradise' will be in equivalent terms, based on effectiveness as a greenhouse gas:

1.68 x 70 = 117.7 $kgCO_2.a^{-1}$

368.3 x 200 = 7.46 $kgCO_2.a^{-1}$

= 125.1 $kgCO_2.a^{-1}$

In terms of gas consumption, there will also be consequential emissions of methane and nitrous oxide, which will also be affected by the efficiency of the appliance converting the energy. From the Energy Consumption: Inhabitation benchmark, the saving in energy typically provided by gas can be derived as 6,669.0 $kWh.a^{-1}$. This value includes the inefficiency of the individual appliance. Therefore the emission will be:

6,669.0 x 0.448 = 2.99 $kgCH_4.a^{-1}$

6,669.0 x 0.00039 = 2.58 $gN_2O.a^{-1}$

Accounting for the equivalent contribution to global warming, based on effectiveness as a greenhouse gas:

2.99 x 70 = 209.1 $kgCO_2.a^{-1}$

2.58 x 200 = 0.5 $kgCO_2.a^{-1}$

= 209.6 $kgCO_2.a^{-1}$

Therefore, the total reduction in the contribution to global warming that would be achieved by moving from the energy consumption of the 'typical' dwelling to the consumption level of the 'urban house in paradise' would be:

1,794.8 + 125.1 + 209.6 **= 2,129.5 $kgCO_2.a^{-1}$**

5.1.16 Energy Generation: Inhabitation

The Energy Generation benchmark measures the contribution made by the use of renewable sources of energy by the dwelling project. Under the definition in *GIR 53* of a zero CO_2 or autonomous dwelling demands that such sources do not contribute to any CO_2 emissions. Therefore, the energy generated by the dwelling has the potential to contribute to a reduction in CO_2 emissions. The ideal benchmark of energy generation is at least equal to that of the Energy Consumption: Inhabitation benchmark, to create a zero energy dwelling. Therefore, the reduction in emissions will be equal to the CO_2 Emissions: Inhabitation benchmark, of 10.7 $kgCO_2.m^{-2}.a^{-1}$. It is important that any reductions a not double counted; including the reduction in emissions created by achieving the benchmark of Energy Consumption: Inhabitation within this criterion would count the reduction twice. However, if the Energy Consumption: Inhabitation benchmark were not achieved, and the Energy Generation level increased as a result, then its contribution to reduction would also increase. Therefore, it is important to view the Consumption and Generation benchmarks as closely interrelated.

If the area of the dwelling, based on typical occupancy figures is 59.8 m^2, then the overall reduction in emissions for the 'urban house in paradise' will be:

10.7 x 59.8 = 639.9 $kgCO_2.a^{-1}$

However, there will also be an additional contribution made through reductions in the emission of methane and nitrous oxide, the other greenhouse gases that are created through the burning of fossil fuels. If the Energy Consumption benchmark is achieved, then the reduction in the consumption of fossil fuels created by the Energy Generation: Inhabitation benchmark will be 25 $kWh.m^{-2}.a^{-1}$. If the area of the dwelling, based on typical occupancy figures is 59.8 m^2, then the overall reduction in fossil fuel consumption will be:

12 x 59.8	= 717.6 $kWh.a^{-1}$ gas
13 x 59.8	= 777.4 $kWh.a^{-1}$ electricity

The emissions of CH_4 and N_20 that are associated with the burning of these fuel types have been determined under the Energy Consumption: Inhabitation benchmark. Therefore, the emissions that would be created by these energy consumption values can be determined as:

717.6 x 0.448	= 321.5 $gCH_4.a^{-1}$
777.4 x 1.350	= 1,049.5 $gCH_4.a^{-1}$
	= 1,371.0 $gCH_4.a^{-1}$

717.6 x 0.00039	= 0.280 $gN_2O.a^{-1}$
777.4 x 0.02997	= 23.299 $gN_2O.a^{-1}$
	= 23.579 $gN_2O.a^{-1}$

As, gramme for gramme, CH_4 contributes 70 times the effect of CO_2 to the greenhouse effect, and N_2O contributes 200 times, in equivalent terms this will equate to a reduction in the contribution to global warming of:

$$1.37 \times 70 \quad = 95.9 \text{ kgCO}_2.\text{a}^{-1}$$

$$0.023 \times 200 \quad = 4.7 \text{ kgCO}_2.\text{a}^{-1}$$

Therefore, in total the contribution to the reduction of greenhouse gas emissions that would be created by achieving the Energy Generation: Inhabitation benchmark would be:

$$639.9 + 95.9 + 4.7 \quad = \mathbf{740.5\ kgCO_2.a^{-1}}$$

5.1.17 Green Space

As green space is an absorber of CO_2, through the process of photosynthesis, the benchmarked provision of greenspace, both as a habitat and as a food provider, will contribute to the net reduction of CO_2 within the atmosphere.

As outlined under the Density: Quantitative criterion, research into the ecological footprint of fossil fuels has determined the most effective assimilators of CO_2 in terms of greenspace, which are forests, can sequester 1.8 tonnes of carbon per hectare.[13] This value can be used to determine the best case scenario for the potential level of annual CO_2 absorption by the greenspace benchmarked to be provided for each dwelling.

Taking the benchmark that a space 25 percent of the floor area of the dwelling will be provided for each new dwelling created, then for a typical occupancy of 2.4 people, this will be 25 percent of 59.8 m^2, or 14.95 m^2. From the relative atomic masses, 1 kgC is the equivalent of 3.67 $kgCO_2$. Therefore, the assimilative capacity of the greenspace will be 6.6 tonnes CO_2 annually per hectare. This can be converted to 0.66 $kgCO_2.m^{-1}.a^{-1}$. For a greenspace with an area of 11.96 m^2, this will equate to:

$$0.66 \times 14.95 \quad = \mathbf{9.87\ kgCO_2.a^{-1}}$$

5.1.18 Lifecycle cost

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the greenhouse effect.

5.1.19 Nitrogen Oxide Emissions from Gas Boilers

The nitrogen oxide emissions from gas boilers benchmarked by the matrix are quantified under the generic term of NO_X emissions. A proportion of this total emission value will be the gas N_2O, which from the Other Green House Gas benchmark analysis can be seen to have a 4 percent relative contribution to the anthropogenic greenhouse effect. From Rodhe, it can be determined that 1 kgN_2O will have an equivalent contribution to the greenhouse effect as 200 kgCO_2.[14] However, as the reduction of N_2O is intrinsically intertwined with the reduction of fossil fuel consumption, the reduction of N_2O emissions will be considered as a part of the contribution to the reduction of global warming made by benchmarks that contribute to the reduction of fossil fuel consumption.

5.1.20 Other Ecological Impacts of Materials

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the greenhouse effect.

5.1.21 Other Greenhouse Gas Emissions

Methane

The reduction in emissions of methane achieved by the benchmarks of the 'urban house in paradise' will be considered under each relevant criterion. For the purposes of comparability, the level of emission will be converted into an equivalent value of CO_2 emission, on the basis of its relative contribution to the greenhouse effect.

HCFCs

The reduction of HCFCs will be achieved through the specification of insulation materials that have been produced without using any of the variants of the gas as blowing agents. It has been possible to determine that the manufacturer Cellotex uses the HCFC 141B as a blowing agent in the production of some insulation materials.[15] The global warming potential of this gas is 150, where CO_2 = 1.[16]

---

[13] Wackernagel, M. and W. Rees. *Our Ecological Footprint*, Oxford: New Society Publishers, 1996.
[14] Rodhe, Henning. 'A Comparison of the Contribution of Various Gases to the Greenhouse Effect', *Science*, 8 June 1990.
[15] Personal communication with Cellotex and Ecotherm Ltd.
[16] Thomas, Randall (ed). Op. Cit.

Despite extensive correspondence being issued to both manufacturers and trade associations, only one manufacturer would supply details of the quantity of HCFC used in the production of insulation foams. In every case where a reason was given for not supplying values, this was due to the confidentiality of such data. Therefore, the calculation of the effect of this benchmark will be based on this value of 140 kgHCFC per tonne of insulation.[17]

The volume of insulation used to construct the analysis model of the 'urban house in paradise', in the Deconstruction and Demolition: Recycling of Materials criterion in the Contribution to Reduction of Natural Resource Consumption parameter, is 22.39 m^3. The volume of one tonne of insulation with a density of 24 $kg.m^{-3}$ is 41.67m^3, which will have an HCFC content of 140 kg. Therefore, the insulation within the dwelling would have an HCFC content of:

$$(22.39 / 41.67) \times 140 \qquad = 75 \text{ kgHCFC}$$

In terms of its relative efficiency as a greenhouse gas, the equivalent mass of CO_2 is:

$$75 \times 150 \qquad = 11,285 \text{ kgCO}_2$$

Spread across the life span of the dwelling, this is an annual equivalent of,

$$11,285 / 120 \qquad = 94.0 \text{ kgCO}_2\text{.a}^{-1}$$

However, this value is based on the assumption that all of the gas encapsulated within the insulation will be released. The value of the proportion of gas released during the manufacture of HCFC insulation is 5 percent.[18] Adopting this proportion gives a value for the reduction in emissions of,

$$94.0 \times 0.05 \qquad = \mathbf{4.70\ kgCO_2.a^{-1}}$$

---

[17] Two values were given by the manufacturer, one of 140 kgHCFC per tonne for foam with a density of 24 $kg.m^{-3}$ and 95 kgHCFC per tonne for foam with a density of 55 $kg.m^{-3}$. The former value is used because the manufacturer states that this is the one most frequently supplied, as it both reduces material costs and has a better value of thermal conductivity.

[18] Personal communication with Mr G. W. Ball, President of the British Rigid Urethane Foam Manufacturer's Association, 25 April 2000. The communication stated that 5 percent of the added blowing agent is lost during manufacture. None is lost during use, and upon demolition the insulation is collected and combusted to destroy the blowing agent without emission to the air, in accordance with a draft EU Directive on demolition waste.

However, this value assumes that the insulation that would be specified in the 'typical' dwelling would always one that used an HCFC blowing agent. Due to the quantity of other materials that do not, this is unlikely.

Tropospheric Ozone

Under the benchmark analysis it was determined that the contribution to the production of tropospheric ozone (O_3), which has a contributory effect to global warming was produced by the emission of both nitrogen oxide (NO) and nitrogen dioxide (NO_2).

The quantitative level of the emission of oxides of nitrogen arising from the burning of fossil fuels in terms of the energy produced can be derived from the *Digest of United Kingdom Energy Statistics 1998*; these are, on average, 0.2 $gNO_X.kWh^{-1}$ for gas appliances and 1.269 $gNO_X.kWh^{-1}$ delivered for electricity.[19] The equivalent contribution of tropospheric ozone to the greenhouse effect can also be determined quantitatively. From Rodhe, one kilogram of tropospheric ozone has the equivalent effect of 1,800 $kgCO_2$.

However, what has not been determined quantitatively are firstly, the specific levels of NO and NO_2 emissions as constituents of the general NO_X value, and secondly the amount of O_3 that is produced as a direct consequence of the emission per unit mass of NO_X and NO and NO_2. Therefore, the effect of the emissions of NO_X on the overall contribution to sustainability is considered under the parameter of Contribution to the Reduction of Pollution, as opposed to this one. Thus the contribution which is made by achieving the benchmarks that have an impact on NO_X emissions will be accounted for, but in direct terms of the quantity of emission rather than the equivalent effect of that emission on global warming. To consider them under both parameters would double count the reduction.

Nitrous Oxide

It has been established from Rodhe that the equivalent contribution of 1 kgN_2O is 200 $kgCO_2$. The effect of N_2O will be considered under the parameters of Energy Consumption and Embodied Energy Consumption, as it is through the reduction in fossil fuel consumption that reductions in the emission of N_2O will be achieved. As it would be impossible to reduce N_2O emissions other than by reducing fossil fuel consumption, it was not considered appropriate to separate then into the Other Greenhouse Gas emissions criterion.

---

[19] Refer to parameter of Prioritising: Contribution to the Reduction of Pollution, Annexe 5.2, and criterion of Energy Consumption: Inhabitation, Annexe 3.16, for the derivation of these values.

5.1.22 Pollution: Energy Consumption during Inhabitation

This benchmark is a measure of the level of pollution that is caused by the energy consumed during the period of inhabitation, measured on a relative scale, per kilowatt-hour. It is related to, but assessed independently of, the Energy Consumption: Inhabitation benchmark, and is intended to ensure that fuels are not used that cause higher levels of pollution when alternatives are available.

As the benchmark is assessed independently of the level of energy consumption, the impact in terms of this parameter need not be considered in terms of both the level of energy consumption in the 'typical' dwelling and the 'urban house in paradise', but rather should be determined on the basis of only the latter.

Therefore, the energy consumption of the 'urban house in paradise', from the Energy Consumption: Inhabitation benchmark is:

$$25 \times 59.8 \qquad = 1495\ kWh.a^{-1}$$

As the impact of some of the pollution emissions under this benchmark will be considered under other parameters, namely those that contribute to pollution not considered by the other four parameters and ozone depletion, the following table shows which are being considered here:

Dwelling	Emissions (g.kWh^{-1} delivered)	
	CH_4	N_2O
'Typical'	0.628	0.006
'u h in p'	0.314	0.003

Emission of methane and nitrous oxide emitted from typical dwelling and 'urban house in paradise'

The level of emissions arising from each benchmark can be determined as,

Typical =	0.628 x 1495	= 938.9 gCH_4.a^{-1}
	0.006 x 1495	= 8.97 g N_2O.a^{-1}
'u h in p' =	0.314 x 1495	= 469.4 gCH_4.a^{-1}
	0.003 x 1495	= 4.49 g N_2O.a^{-1}

Therefore, the reduction in pollutant emissions that contribute to the greenhouse effect which would be achieved by moving from the standard of the 'typical' dwelling to that of the 'urban house in paradise' is,

$$938.9 - 469.4 = 469.5\ gCH_4.a^{-1}$$

$$8.97 - 4.49 = 4.48\ g\ N_2O.a^{-1}$$

Accounting for the equivalent contribution to global warming, based on effectiveness as a greenhouse gas in the contribution to greenhouse gas emissions will be:

$$469.5 \times 70 = 32.9\ kgCO_2.a^{-1}$$

$$4.48 \times 200 = 0.90\ kgCO_2.a^{-1}$$

$$= \mathbf{33.8\ kgCO_2.a^{-1}}$$

5.1.23 Procurement strategy

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the greenhouse effect.

5.1.24 Quality of Internal Environment: Indoor Pollution

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the greenhouse effect.

5.1.25 Quality of Internal Environment: Daylight

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the greenhouse effect.

5.1.26 Quality of Internal Environment: Ventilation and Air Tightness

The Energy Consumption: Inhabitation criterion will determine the contribution made to the reduction in emissions through improvements in the efficiency of a number of factors that contribute to the overall energy consumption of the dwelling. However, reducing the heat loss that occurs through the ventilation rate and the air tightness of the dwelling's structure and fabric, as a contributor to this saving, will have a lesser impact upon reducing the energy consumption.

In order to determine the magnitude of these effects, the model of the 'urban house in paradise' that was developed for the Contribution to the Reduction of Natural Resources parameter, defined by a number of the benchmarks, will be used also. This will assist in the purposes of relative comparability of data. Two scenarios were taken, firstly of a dwelling with natural ventilation and an air tightness value both representative of a 'typical' dwelling, and secondly to the standards of the Quality of the Internal Environment: Ventilation and Air tightness benchmark of the 'urban house in paradise'. The annual energy consumption was determined using the SAP model for both scenarios.

The reduction in energy consumption for space heating was determined as 1,966.7 $kWh.a^{-1}$. The increase in energy consumption as a result of the additional fans was determined as 59.8 $kWh.a^{-1}$. The emissions that will arise out of the reduction and consumption can be determined as:

Inhabitation:

Space heating (gas):	1,966.7 x 0.21	= 413.0 $kgCO_2.a^{-1}$
	1,966.7 x 0.448	= 881.1 $gCH_4.a^{-1}$
	1,966.7 x 0.00039	= 0.77 $gN_2O.a^{-1}$

Accounting for the equivalent contribution to global warming, based on effectiveness as a greenhouse gas, the emission of CH_4 and N_2O during the period of inhabitation will be:

881.1 x 70	= 61.7 $kgCO_2.a^{-1}$
0.77 x 200	= 0.15 $kgCO_2.a^{-1}$
	= 61.8 $kgCO_2.a^{-1}$

Therefore, the total reduction in greenhouse gas emissions, in equivalent terms, from the reduction in energy consumption due to the increased air tightness and controlled ventilation rate will be:

413.0 + 61.8	= 474.8 $kgCO_2.a^{-1}$

The additional energy consumption, that powers the fans, will be electrical:

Electricity:	59.8 x 0.36	= 21.5 $kgCO_2.a^{-1}$
	59.8 x 1.350	= 80.7 $gCH_4.a^{-1}$
	59.8 x 0.02997	= 1.79 $gN_2O.a^{-1}$

Accounting for the equivalent contribution to global warming, based on effectiveness as a greenhouse gas, the emission of CH_4 and N_2O arising from the embodied energy will be:

80.7 x 70	= 5.65 $kgCO_2.a^{-1}$

$$1.79 \times 200 \qquad = 0.36\ kgCO_2.a^{-1}$$

$$= 6.01\ kgCO_2.a^{-1}$$

Therefore, the effect on greenhouse gas emissions, in equivalent terms, due to the reduction in infiltration and ventilation rates will be:

$$21.5 + 6.01 \qquad = 27.5\ kgCO_2.a^{-1}$$

Therefore, the reduction in greenhouse gas emissions created by increasing the thermal performance of the dwelling to the benchmark of the 'urban house in paradise' will be:

$$474.8 - 27.5 \qquad = \mathbf{447.3\ kgCO_2.a^{-1}}$$

This value must be treated with a degree of caution. As this criterion was concerned only with the direct effects of reducing the ventilation and infiltration rates, all other parameters were kept constant during the energy consumption modelling. Therefore no account is made of the consequent impacts of increasing the standard. These will be accounted for collectively by the Energy Consumption: Inhabitation criterion.

5.1.27 Recycling of Construction Waste

From the benchmark analysis it was determined that construction waste can be typically averaged as 10 percent of the total quantity of materials. As for the Deconstruction and Demolition: Recycling of Materials criterion, the materials that will contribute to the emission of greenhouse gases will be the organic putrescible content of the construction waste. This will be the timber content for the materials identified in the primary bulk material analysis; the total value of which was 2,285 kg. If the typical waste level is taken as 10 percent, and the 'urban house in paradise' benchmark as 2.5 percent, then the reduction in timber waste sent to landfill will be:

$$2285 \times 0.1 \qquad = 228.5\ kg$$

$$2285 \times 0.025 \qquad = 57.1\ kg$$

$$\therefore \text{ reduction} = 228.5 - 57.1 \qquad = 171.4\ kg$$

Spread across the life span of the dwelling, this would equate to an equivalent annual reduction of:

$$171.4 / 120 \qquad = 1.43\ kg.a^{-1}$$

The quantity of timber that will decompose will be 50 percent of the total sent to landfill; the rest will remain inert. For each kilogram of waste disposed of by landfill, 0.15 $kgCH_4$ and 0.39 $kgCO_2$ will be produced.[20] Therefore, the emissions of CH_4 and CO_2 as a result of the waste disposed of per annum will be:

$$(1.43 / 2) \times 0.15 = 0.11 \text{ kgCH}_4$$

$$(1.43 / 2) \times 0.39 = 0.28 \text{ kg CO}_2$$

From Rodhe, each kilogram of CH_4 emitted into the atmosphere has the equivalent effect of 70 kilograms of CO_2. Therefore, the total equivalent CO_2 emission will be:

$$(0.11 \times 70) + 0.28 = 7.98 \text{ kgCO}_2$$

However, it must be remembered that this value represents the total quantity of gas that is produced by the waste over the total period of decomposition of at least 50 years, therefore this will translate to an annual emission of:

$$7.98 / 50 = \mathbf{0.16\ kgCO_2.a^{-1}}$$

5.1.28 Recyclability of Building: Adaptability

In terms of its benchmark value, this criterion is considered to have no directly measurable consequential reduction upon the greenhouse effect.

5.1.29 Space Standards: Area

Increasing the space standards of the dwelling will have an impact on the overall CO_2 emission of that dwelling. The units of magnitude for the Ecological Weight: CO_2 Emission of Materials are $kgCO_2.m^{-2}$, and for the CO_2 Emissions: Inhabitation are also $kgCO_2.m^{-2}$, and are therefore affected by changes in the area of the dwelling.

For the average occupancy of dwellings in the United Kingdom, of 2.4, the Space Standards analysis gives a typical dwelling area of 48.5 m^2; for the 'urban house in paradise' this rises to 59.8 m^2, an increase of 11.3 m^2.

Therefore, the increase CO_2 emission that will occur as a result of the average increase in Space standards will be:

---

20 Tchobanoglous, George, Hilary Theisen and Rolf Eliassen. *Solid Wastes – Engineering Principles*

embodied in materials	(11.3 x 90) / 120	= 8.48 $kgCO_2.a^{-1}$
during inhabitation	11.3 x 10.7	= 120.9 $kgCO_2.a^{-1}$
Total		= 129.4 $kgCO_2.a^{-1}$

However, this will not be the only effect that an increase in Space Standards has upon the emission of greenhouse gases. There will also be emissions of CH_4 and N_2O during the period of inhabitation and from the embodied energy consumed.

To complete the emissions during inhabitation, the emissions of CH_4 and N_2O that will arise due to the increase in area is:

11.3 x 15	= 169.5 kWh gas
11.3 x 10	=113.0 kWh electricity

Gas:	169.5 x 0.448	= 75.9 $gCH_4.a^{-1}$
	169.5 x 0.00039	= 0.066 gN_2O/a
Electricity:	113.0 x 1.350	= 152.6 $gCH_4.a^{-1}$
	113.0 x 0.02997	= 3.39 $gN_2O.a^{-1}$
		= 228.5 $gCH_4.a^{-1}$
		= 3.45 $gN_2O.a^{-1}$

Accounting for the equivalent contribution to global warming, based on effectiveness as a greenhouse gas, the emission of CH_4 and N_2O during the period of inhabitation will be:

226.2 x 70	= 16.0 $kgCO_2.a^{-1}$
3.45 x 200	= 0.69 $kgCO_2.a^{-1}$
	= 16.7 $kgCO_2.a^{-1}$

The greenhouse gas emissions that arise due the increase in area that are attributable to the embodied energy consumption of the dwelling can be determined as:

Embodied energy:	(11.3 x 250) / 120	= 23.5 $kWh.a^{-1}$
Electricity:	7.85 x 1.350	= 10.6 $gCH_4.a^{-1}$
	7.85 x 0.02997	= 0.24 $gN_2O.a^{-1}$

---

and Management Issues, London: McGraw-Hill, 1977.

Gas: 7.85×0.448 $= 3.52\ gCH_4.a^{-1}$

7.85×0.00039 $= 0.0031\ gN_2O.a^{-1}$

Petroleum 7.85×0.162 $= 0.97\ gCH_4.a^{-1}$

9.41×0.12378 $= 1.16\ gN_2O.a^{-1}$

$= 15.4\ gCH_4.a^{-1}$

$= 1.21\ gN_2O.a^{-1}$

Accounting for the equivalent contribution to global warming, based on effectiveness as a greenhouse gas, the emission of CH_4 and N_2O arising from embodied energy consumption will be:

15.4×70 $= 1.08\ kgCO_2.a^{-1}$

1.21×200 $= 0.24\ kgCO_2.a^{-1}$

$= 1.32\ kgCO_2.a^{-1}$

Therefore, in total the effects of the Space Standards: Area benchmark on the contribution to the reduction of greenhouse gas emissions will be:

$129.4 + 16.5 + 1.32$ $= 147.22\ kgCO_2.a^{-1}$

It should be emphasised that this value is an increase in emission, rather than a reduction. In the interests of continuity, it will be conceived of as a negative contribution to the reduction of the greenhouse effect and would, therefore, have a value of,

$= -147.2\ kgCO_2.a^{-1}$

5.1.30 Space Standards: Volume

The increase in volume of the dwelling by this benchmark will be achieved by an increase in the area of the dwelling, as well as its internal height. As the level of CO_2 emission is quantified per unit area, the increase in the volume of the dwelling will be considered to be the same as that of the increase in area, benchmarked by the Space Standards: Area criterion. The additional space to be heated that is created by the increase in internal height will be accounted for within the SAP method of determining energy consumption, and thus in the methodology used to determine the consequent CO_2 emissions. Therefore, the increase in height will be accounted for when determining the performance of a dwelling against the benchmark of CO_2 emissions, and so the additional effect need not be considered in terms of prioritising. Thus the contribution is the same as that of the Space Standards: Area criterion.

$= -147.2\ kgCO_2.a^{-1}$

5.1.31 Thermal Performance

The Energy Consumption: Inhabitation criterion will determine the contribution made to the reduction in emissions through improvements in the efficiency of a number of factors that contribute to the overall energy consumption of the dwelling. However, there will be a lesser benefit through solely increasing the thermal performance of the fabric of the dwelling; this value will also be affected by the increase in the embodied energy of the fabric.

In order to determine the magnitude of these effects, the model of the 'urban house in paradise' that was developed for the Contribution to the Reduction of Natural Resources parameter, defined by a number of the benchmarks, will be used also. This will assist in the purposes of relative comparability of data. Two scenarios were taken, firstly with the dwelling insulated to current Building Regulation standards, and secondly to the standards of the Thermal Performance benchmark of the 'urban house in paradise'. The annual energy consumption, determined using the SAP model for both scenarios, and the embodied energy of the additional insulation were calculated.

The reduction in energy consumption for space heating was determined as 569 $kWh.a^{-1}$. The increase in the embodied energy was determined as 5,395 kWh; spread across the design life span of the dwelling this would equate to an annual equivalent value of 45.0 $kWh.a^{-1}$. The emissions that will arise out of the reduction and consumption can be determined as:

Inhabitation:

Space heating (gas):	569 x 0.448	$= 254.9\ gCH_4.a^{-1}$
	569 x 0.00039	$= 0.22\ gN_2O.a^{-1}$

Accounting for the equivalent contribution to global warming, based on effectiveness as a greenhouse gas, the emission of CH_4 and N_2O during the period of inhabitation will be:

254.9 x 70	$= 17.8\ kgCO_2.a^{-1}$
0.22 x 200	$= 0.04\ kgCO_2.a^{-1}$
	$= 17.9\ kgCO2.a^{-1}$

From the SAP Procedure documentation, it can be determined that the CO_2 emission arising from gas consumption, in terms of $kgCO_2.kWh^{-1}$ delivered, is 0.21 $kgCO_2.kWh^{-1}$.

$$569 \times 0.21 = 119.5\ kgCO_2.a^{-1}$$

Therefore, the total reduction in greenhouse gas emissions, in equivalent terms, from the reduction in energy consumption due to the increased thermal performance will be:

$$17.9 + 119.5 = 137.4\ kgCO_2.a^{-1}$$

Embodied (1:1:1):

Electricity:	15.0 x 1.350	= 20.2 $gCH_4.a^{-1}$
	15.0 x 0.02997	= 0.45 $gN_2O.a^{-1}$
Gas:	15.0 x 0.448	= 6.72 $gCH_4.a^{-1}$
	15.0 x 0.00039	= 0.006 $gN_2O.a^{-1}$
Petroleum	15.0 x 0.162	= 2.43 $gCH_4.a^{-1}$
	15.0 x 0.12378	= 1.86 $gN_2O.a^{-1}$
		= 29.3 $gCH_4.a^{-1}$
		= 2.32 $gN_2O.a^{-1}$

Accounting for the equivalent contribution to global warming, based on effectiveness as a greenhouse gas, the emission of CH_4 and N_2O arising from the embodied energy will be:

29.3 x 70	= 2.05 $kgCO_2.a^{-1}$
2.32 x 200	= 0.46 $kgCO_2.a^{-1}$
	= 2.50 $kgCO_2.a^{-1}$

During the analysis for the Ecological Weight: Embodied CO_2 benchmark, it was derived that the typical emission per unit of embodied energy is 0.36 $kgCO_2.kWh^{-1}$.

$$15.0 \times 0.36 = 5.40\ kgCO_2.a^{-1}$$

The total emissions of greenhouse gas, in equivalent terms, due to the additional embodied energy consumed to achieve the thermal performance benchmark is:

$$2.50 + 5.40 = 7.9\ kgCO_2.a^{-1}$$

Therefore, the reduction in greenhouse gas emissions created by increasing the thermal performance of the dwelling to the benchmark of the 'urban house in paradise' is:

$$137.4 - 7.9 \qquad = \mathbf{129.5\ kgCO_2.a^{-1}}$$

This value must be treated with a degree of caution. As this criterion was concerned only with the direct effects of increasing the thermal performance, all other parameters were kept constant during the energy consumption modelling. Therefore no account is made of the consequent impacts of increasing the standard, such as affects on the type of heating system that would be specified. All of these will be accounted for collectively by the criterion of Energy Consumption: Inhabitation.

5.1.32 Use of Recycled Materials

As with the Domestic Waste criterion whilst there will be an embodied energy consumption, and therefore consequent CO_2 emission, associated with the processing of recycled materials, the effect of this will be considered to be the equivalent of that consumed and emitted by the processing of virgin materials. Therefore, this will be accounted for within the Ecological Weights criteria. Through the use of reclaimed timber, there will be a contribution to reducing atmospheric CO_2 through a reduction in tree felling. Quantifying this will be dependent upon determining the area of forest per tonne of timber consumed. Also there will be a reduction through the materials not sent to landfill.

5.1.32 Use of Renewable Raw Materials

Through the use of renewable source timber, there will be a contribution to reducing atmospheric CO_2 through a reduction in tree felling. However, in terms of its benchmark value, this criterion is not considered to have a direct consequential reduction upon the greenhouse effect.

5.1.33 Utilisation of Local Resources

The only determinable effect that the utilisation of local resources may have on the reduction of pollution emissions will be through the reduction in transport. It has not been possible to determine the magnitude of total energy consumed through this criterion, and the mix of fuel types that would be used. Also, a benchmark for the typical dwelling could not be determined. Therefore it is not possible to establish the relative contribution of this criterion to the parameter of the reduction of greenhouse gas emissions.

5.1.34 Water Consumption: Construction

From the benchmark analysis of this criterion, it was determined that the typical and 'urban house in paradise' benchmarks of water consumed during the construction of the dwelling are 34.1 and 8.5 litres per square metre. For the average occupancy of dwellings in the United Kingdom, of 2.4, the Space Standards analysis gives a typical dwelling area of 48.5 m^2; for the 'urban house in paradise' this rises to 59.8 m^2. Therefore, the quantity of water consumed in the construction of these two dwellings can be determined as,

48.5 x 34.1	= 1,653.8 litres
59.8 x 8.5	= 508.3 litres
∴ reduction	= 1,144.7 litres

Accounting for the life span of the dwelling, the annual equivalent reduction will be:

1,144.7 / 120	= 9.54 $litres.a^{-1}$

During the analysis to determine the benchmark of Water Consumption: Inhabitation, it was established that, 1 litre of mains water per day equates to the emission of 0.33 $kgCO_2$ per annum. Therefore, the reduction of 9.54 $litres.a^{-1}$ will equate to a reduction of 0.00933 $kgCO_2.a^{-1}$.

It was also determined that the reduction of 153.5 litres of potable water consumption per person per day will equate to an energy reduction of 0.08 kWh of energy per day. Therefore, the reduction of 9.54 litres per annum will equate to an energy reduction of 0.005 $kWh.a^{-1}$. The generation of that energy will also create an emission of methane and nitrous oxide, which will have a contributory effect on global warming. For the purposes of this calculation, it will be assumed that all of this energy will be electricity. The CH_4 and N_2O emissions associated with the generating of this energy, by using the figures set out above in the Energy Consumption: Inhabitation criterion, by fossil fuels will be:

0.005 x 1.350	= 0.0068 $gCH_4.a^{-1}$
0.005 x 0.02997	= 0.00015 $gN_2O.a^{-1}$

As CH_4 is 70 times as potent as a greenhouse gas than CO_2, the equivalent emission will be:

0.0068 x 70	= 0.476 $kgCO_2.a^{-1}$

As N_2O is 200 times as potent as a greenhouse gas than CO_2, the equivalent emission will be:

$$0.00015 \times 200 = 0.0300\ kgCO_2.a^{-1}$$

Therefore, in total the contribution to the reduction of greenhouse gas emissions created by the benchmark of water consumption will be:

$$0.00933 + 0.476 + 0.0300 \quad = \mathbf{0.515\ kgCO_2.a^{-1}}$$

5.1.35 Water Consumption: Inhabitation

In the Water Consumption: Inhabitation benchmark, it was shown that the energy consumed in the supply and disposal of 600 litres of domestic mains water each day resulted in the emission of 200 $kgCO_2$ per annum. Therefore, 1 litre of mains water per day equates to the emission of 0.33 $kgCO_2$ per annum. The typical mains water consumption, determined during the analysis of the benchmarks, is 160 litres per person per day. This equates to an emission level of 53.3 $kgCO_2.a^{-1}$.

For the 'urban house in paradise' the level of mains consumption is benchmarked as 6.5 litres per person per day. The energy consumed during the provision of that water will be 1.4 $kWh.a^{-1}$, and the energy consumed during the treatment and disposal of 62.2 litres will be 10.3 $kWh.a^{-1}$. This total of 11.9 kWh per person per year equates to a CO_2 emission of 10.8 $kgCO_2.p^{-1}.a^{-1}$.

Therefore, the reduction in emission achieved by the benchmark of the 'urban house in paradise' over that of the typical dwelling will be, 53.3 – 10.8 = 42.2 $kgCO_2.p^{-1}.a^{-1}$. At an average occupancy of 2.4 people per dwelling, this equates to a reduction in emission per typical dwelling of,

$$= 101.2\ kgCO_2.a^{-1}$$

During the analysis to determine the benchmark of Water Consumption: Inhabitation, it was determined that the reduction of 153.5 litres of potable water consumption per person per day will equate to an energy saving of 0.08 kWh of energy per day. Across the period of a year this will equate to an annual reduction of 29.2 kWh. Based on the mean occupancy figures for dwellings in the United Kingdom of 2.4 people per dwelling, this will equate to an annual household reduction of 70.1 kWh, if the benchmark for the 'urban house in paradise' is achieved. The generation of that 70.1 kWh will also create an emission of methane and nitrous oxide, which will have a contributory effect on global warming. For the purposes of this calculation, it will be assumed that all of this energy will be electricity. The CH_4 and N_2O emissions associated with the generating of this energy, by using the figures set out above in the Energy Consumption: Inhabitation criterion, by fossil fuels will be:

$$70.1 \times 1.350 = 94.6\ gCH_4.a^{-1}$$
$$70.1 \times 0.02997 = 2.10\ gN_2O.a^{-1}$$

As CH_4 is 70 times as potent as a greenhouse gas than CO_2, the equivalent emission will be:

$$94.6 \times 70 = 6.62\ kgCO_2.a^{-1}$$

As N_2O is 200 times as potent as a greenhouse gas than CO_2, the equivalent emission will be:

$$2.10 \times 200 = 0.420\ kgCO_2.a^{-1}$$

Therefore, in total the contribution to the reduction of greenhouse gas emissions created by the benchmark of water consumption will be:

$$101.2 + 6.62 + 0.420 = \mathbf{108.2\ kgCO_2.a^{-1}}$$

5.2 Prioritising – Contribution to the Reduction of Pollution

To prioritise the benchmarks for this parameter the quantity of the reduction of any pollutant arising directly in connection with the criterion will be determined. This will be the reduction that will be achieved by moving from the benchmark of the 'typical' dwelling to the benchmark of the 'urban house in paradise'. If there is more than one pollutant per criterion, such as for Ecological Weight: Embodied Energy, they will be added together to provide a total value. For the purposes of comparability, If the value is a one-off emission as opposed to an annual one, it will be normalised across the life span of the dwelling to provide an annual equivalent value.

The following presents how the emissions per annum will be determined for each criterion, where applicable.

5.2.1 CO_2 Emissions: Construction and Deconstruction

The emissions of CO_2 have already been quantified under the parameter of Contribution to the Reduction of Global Warming. To include it under this parameter also would double count its contribution the overall reduction of environmental degradation.

5.2.2 CO_2 Emissions: Inhabitation

The emissions of CO_2 have already been quantified under the parameter of Contribution to the Reduction of Global Warming. To include it under this parameter would also double count its contribution the overall reduction of environmental degradation.

5.2.3 Carbon Intensity

The emissions of CO_2 have already been quantified under the parameter of Contribution to the Reduction of Global Warming. To include it under this parameter also would double count its contribution the overall reduction of environmental degradation.

5.2.4 Construction Period

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.5 Contextual Significance of the Site

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.6 Deconstruction and Demolition: Recycling of Materials

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.7 Design Life Span

The contribution of the design life span benchmark to the reduction of pollution will be the cumulative effect of increasing the design life span of the dwelling by 60 years. To determine this, each criterion, where applicable, will be taken individually and then the contributions all summed.

Ecological Weight: Embodied Energy

On the basis of the average occupancy level and the Space Standards: Area benchmark, the embodied energy for the 'urban house in paradise' is 59.8 x 250 = 14,950 kWh. Therefore, the effect of the design life span benchmark will be:

14,950 / 60	= 249.2 $kWh.a^{-1}$
14,950 / 120	= 124.6 $kWh.a^{-1}$
∴ effect of life span	= 124.6 $kWh.a^{-1}$

The pollution emissions associated with this reduction are:

Electricity:	41.5 x 3.167	= 131.6 $gSO_2.a^{-1}$
	41.5 x 0.353	= 14.7 $gPM10.a^{-1}$
	41.5 x 0.903	= 37.5g $NOx.a^{-1}$
	41.5 x 0.581	= 24.1 $gCO.a^{-1}$
Gas:	41.5 x 0.008	= 0.33 $gSO_2.a^{-1}$
	41.5 x 0.004	= 0.17 $gPM10.a^{-1}$
	41.5 x 0.372	= 15.4 g $NOx.a^{-1}$
	41.5 x 0.011	= 0.46 $gCO.a^{-1}$
Petroleum	41.5 x 0.642	= 26.7 $gSO_2.a^{-1}$
	41.5 x 0.572	= 23.8 $gPM10.a^{-1}$
	41.5 x 5.894	= 244.8g $NOx.a^{-1}$
	41.5 x 3.380	= 140.4 $gCO.a^{-1}$

$= 158.6\ gSO_2.a^{-1}$

$= 38.6\ gPM10.a^{-1}$

$= 293.7\ g\ NOx.a^{-1}$

$= 170.0\ gCO.a^{-1}$

$= 664.4\ g\ pollution.a^{-1}$

Energy Consumption: Construction Processes

The pollution emissions created by these processes will be included within the overall calculation of the Ecological Weight: Embodied Energy criterion, and therefore should not be included here so that its effect is not double counted when the cumulative total is determined.

Standards: Area and Volume

Although during the calculation of the effect of the Space Standards: Area and Volume benchmarks on pollutant emission the design life span of the dwelling was used, it will not be a part of the cumulative effect of the design life span benchmark. The Ecological Weight: Embodied Energy criterion has already taken account of the increase in area created by the Space Standards benchmark.

Thermal Performance

The impact of increasing the level of thermal performance of the dwelling's fabric will be accounted for within the Ecological Weight: Embodied Energy criterion, and will not be assessed here so as no to double count when calculating the cumulative effect.

Therefore, in total the reduction in the emission of pollutants achieved through increasing the design life span of the dwelling to the benchmark of the 'urban house in paradise' will be:

644.6 $= \mathbf{644.6\ g\ pollution.a^{-1}}$

5.2.8 Density: Quantitative

As for the diversity criterion below, benchmarking the density to the level proposed by Friends of the Earth, which is based on thresholds at which public transport and walking become more chosen options, will have a reduction in private transport use, with consequential reduction in the pollution generated by such transportation. The consequent emissions arising from different modes of transport is shown in the following table.

Emission Type	Emissions by Mode of Transport (g.t^{-1}.km)		
	Road	Rail	Water
Carbon dioxide	211	102	33
Carbon monoxide	0.90	0.02	0.11
Hydrocarbons	0.68	0.01	0.05
Nitrogen dioxide	2.97	1.01	2.26
Particulate matter	0.39	0.01	0.02
Sulphur dioxide	0.20	0.07	0.04

Pollution Emissions by Different Modes of Transport

However, due to the complexities involved in determining a quantitative reduction it is beyond the scope of this study to undertake an analysis of the magnitude of such reduction in terms of the benchmark proposed.

5.2.9 Density: Qualitative

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.10 Diversity: Programme

In terms of its benchmark value, this criterion is considered to have no direct consequential effect on pollution. As for greenhouse gas emissions, an indirect effect that creating a mixed-use project would be through the reduction in emissions arising from transport through providing facilities within walking distance. However, it is beyond the scope of this study to undertake an analysis of the magnitude of such reduction in terms of the programmatic diversity benchmark proposed.

5.2.11 Domestic Waste

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.12 Ecological Significance of the Site

Under the Density: Qualitative criterion, it was determined that the mean occupancy level of 2.4 people per dwelling, 80 m^2 of land will be attributable to each dwelling. The Ecological Significance of the Site benchmark states that 100 percent of the land used by the 'urban house in paradise' will be brownfield as opposed to greenfield. Whist plants within greenspace absorb CO_2, as has been quantified under the Contribution to the Reduction of the Greenhouse Effect parameter, they can also absorb other forms of pollution.[1] However, different species have varying capabilities in the rate of absorption, and different rates of absorption for different pollutants for a given species; therefore it would be difficult to attribute a quantitative value just on the basis of the quantity of green space provided, with no qualification as to the species within that green space.

5.2.13 Ecological Weight: Embodied Energy

Whist the emissions of gases that contribute to the greenhouse effect have been determined under another parameter, there would also be emissions of other gases associated with the combustion of fossil fuels to fulfil the embodied energy demands of the dwelling.

The benchmark analysis can be used to determine comparable embodied energy values for a 'typical' dwelling and an 'urban house in paradise' based on the Space Standards: Area benchmark, using the average occupancy level from census data, and the Ecological Weight: Embodied Energy benchmark:

'typical' = 1,000 x 48.5 = 48,500 kWh

'urban house in paradise' = 250 x 59.8 = 14,950 kWh

Therefore, the reduction in embodied energy that will be achieved through the benchmark reduction is:

48,500 – 14,950 = 33,550 kWh

Divided across the design life span of the dwelling, this is the equivalent annual reduction of:

33,500 / 120 = 279.2 $kWh.a^{-1}$

The Building Research Establishment's *Methodology for Environmental Profiles* determines the emissions associated with fuel consumption from the NETCEN National Atmospheric

[1] Vale, Brenda and Robert. 'Green Architecture?', *Building Services*, October 1990.

Emissions Inventory, based on 1996 figures which are the most recent available.[2] These figures also take into account the upstream emissions arising from the extraction, refining, and supply, as well as the energy consumed in extraction, refining and supply of the energy to conduct to processes. These emissions are summarised in the following table.

Pollutant	Emission factors of fossil fuels ($g.kWh^{-1}$)		
	Gas	Oil	Coal
SO_2	0.007	0.555	2.848
PM10	0.004	0.050	0.315
NOx	0.334	0.480	0.564
CO	0.010	0.051	0.518

Pollutant emission factors for different fuel types

In terms of generating electricity, accounting for the inefficiencies of power stations and transmission after generation means that per kWh of delivered energy the emissions are as summarised in the following table.

Pollutant	Emission factors ($g.kWh^{-1}$ delivered electricity)		
	Gas	Oil	Coal
SO_2	0.018	1.388	9.493
PM10	0.010	0.125	1.050
NOx	0.835	1.200	1.880
CO	0.025	0.128	1.727

Pollutant emission factors for different fuel types per kWh of delivered electricity

On the basis of the fossil fuel mix used to generate electricity, derived from the Digest of United Kingdom Energy Statistics 1998[3] (33 percent coal, 31 percent gas, 26 percent nuclear and 2 percent oil), it can be determined that to generate one kWh of electricity will create the following emissions form each fuel type.

[2] Howard, Nigel, Suzy Edwards and Jane Anderson. *BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings*. London: Construction Research Communications Limited, 1999.

[3] Department of Trade and Industry. *Digest of United Kingdom Energy Statistics 1998*, London: HMSO, 1998.

Pollutant	Emission on the basis of generation mix (g.kWh⁻¹)			
	Gas	Oil	Coal	TOTAL
SO_2	0.006	0.028	3.133	3.167
PM10	0.003	0.003	0.347	0.353
NOx	0.259	0.024	0.620	0.903
CO	0.008	0.003	0.570	0.581

Pollutant emission factors per kWh of on the basis of generation mix

The values for natural gas and petroleum consumption will account for the typical relative efficiency of appliances consuming those sources.[4]

Assuming a 1:1:1 ratio for the mixture of electricity:gas:petroleum for fuel types used during the period of embodied energy consumption gives a value per fuel type of 93.1 $kWh.a^{-1}$. Therefore, the emissions associated with each fuel are:[5]

Electricity:	93.1 x 3.167	= 294.7 $gSO_2.a^{-1}$
	93.1 x 0.353	= 32.8 $gPM10.a^{-1}$
	93.1 x 0.903	= 84.0 g $NOx.a^{-1}$
	93.1 x 0.581	= 54.1 $gCO.a^{-1}$
Gas:	93.1 x 0.008	= 0.74 $gSO_2.a^{-1}$
	93.1 x 0.004	= 0.37 $gPM10.a^{-1}$
	93.1 x 0.372	= 34.6 g $NOx.a^{-1}$
	93.1 x 0.011	= 1.02 $gCO.a^{-1}$
Petroleum	93.1 x 0.642	= 59.7 $gSO_2.a^{-1}$
	93.1 x 0.572	= 53.2 $gPM10.a^{-1}$
	93.1 x 5.894	= 548.7 g $NOx.a^{-1}$
	93.1 x 3.380	= 314.5 $gCO.a^{-1}$

Therefore, in total the reduction in pollutant emissions will be:

---

[4] Thomas, Randall (ed). *Environmental Design*, London: E & F N Spon, 1996.

[5] The values determined for NOx emissions have had the N_2O component deducted from the NOx total, as N_2O emissions are counted under the parameter of Contribution to the Reduction of the Greenhouse Effect; not removing them for the Contribution to the Reduction of Pollution parameter would double count them.

$= 355.1\,gSO_2.a^{-1}$

$= 86.4\,gPM10.a^{-1}$

$= 667.3\,g\,NOx.a^{-1}$

$= 369.6\,gCO.a^{-1}$

= 1,478.4 g pollution.a^{-1}

5.2.14 Ecological Weight: Embodied CO_2 emission

The emissions of CO_2 have already been quantified under the parameter of Contribution to the Reduction of Global Warming. To include it under this parameter also would double count its contribution the overall reduction of environmental degradation.

5.2.15 Energy Consumption: Construction Processes

As for the other criteria that benchmark a reduction in the consumption of fossil fuel, there will also be a reduction in other pollutants. The reduction in energy consumption during on site construction can be determined from the benchmark analysis. From the mean occupancy value, Space Standards: Area and Energy Consumption: Construction Processes benchmarks, the reduction in energy consumption can be determined as:

'typical':	150 x 48.5	= 7,275 kWh
'urban house in paradise'	75 x 59.8	= 4,485 kWh
∴ reduction =	7,275 – 4,485	= 2,790 kWh

Across the design life span of the dwelling, this will equate to an annual equivalent reduction of:

2,790 / 120 $= 23.3\,kWh.a^{-1}$

In terms of fuel mix, gas will not be used as much for a fuel source during on site construction, and therefore the ratio has been proposed as 4.5:4.5:1 for electricity:petroleum:gas.

Therefore, the reduction in the emissions of pollutant emissions by fuel type will be:

Electricity:	10.5 x 3.167	$= 33.3\,gSO_2.a^{-1}$
	10.5 x 0.353	$= 3.71\,gPM10.a^{-1}$
	10.5 x 0.903	$= 9.48\,g\,NOx.a^{-1}$
	10.5 x 0.581	$= 6.10\,gCO.a^{-1}$

Gas:	2.33 x 0.008	= 0.02 $gSO_2.a^{-1}$
	2.33 x 0.004	= 0.01 $gPM10.a^{-1}$
	2.33 x 0.372	= 0.87 g $NOx.a^{-1}$
	2.33 x 0.011	= 0.03 $gCO.a^{-1}$
Petroleum	10.5 x 0.642	= 6.74 $gSO_2.a^{-1}$
	10.5 x 0.572	= 6.01 $gPM10.a^{-1}$
	10.5 x 5.894	= 61.9 g $NOx.a^{-1}$
	10.5 x 3.380	= 35.5 $gCO.a^{-1}$

Therefore, in total the reduction in pollutant emissions will be:

= 40.1 $gSO_2.a^{-1}$

= 9.73 $gPM10.a^{-1}$

= 72.5 g $NOx.a^{-1}$

= 41.6 $gCO.a^{-1}$

= 163.9 g pollution.a^{-1}

5.2.16 Energy Consumption: Inhabitation

The values for the emissions per kWh for each fossil fuel type, derived under the Ecological Weight: Embodied Energy in Materials, can be used to determine the emissions from the energy consumed during the period of inhabitation. The electricity saved by moving from the energy consumption of the 'typical' dwelling to that of the 'urban house in paradise' would be:

Typical spec built dwelling	= 48.5 x 38	= 1,843
'urban house in paradise'	= 59.8 x 10	= 598
	∴ reduction	= 1,245 kWh.a^{-1} electricity

Therefore, the reduction in pollutant emissions as a result of the reduction in electricity consumption will be:

1,245 x 3.167	= 3,942.9 $gSO_2.a^{-1}$
1,245 x 0.353	= 439.5 $gPM10.a^{-1}$
1,245 x 0.903	= 1,124.2 $gNOx.a^{-1}$
1,245 x 0.581	= 723.4 $gCO.a^{-1}$

In terms of gas consumption, there will also be consequential emissions of pollutants, which will also be affected by the efficiency of the appliance converting the energy. From the Energy Consumption: Inhabitation benchmark, the saving in energy typically provided by gas can be derived as 6,669.0 $kWh.a^{-1}$. This value includes the inefficiency of the individual appliance. Therefore the emissions will be:

$$6,669.0 \times 0.008 = 53.4\ gSO_2.a^{-1}$$
$$6,669.0 \times 0.004 = 26.7\ gPM10.a^{-1}$$
$$6,669.0 \times 0.372 = 2,480.9\ g\ NOx.a^{-1}$$
$$6,669.0 \times 0.011 = 73.4\ gCO.a^{-1}$$

Therefore, in total the reduction in pollutant emissions will be:

$$= 3,996.3\ gSO_2.a^{-1}$$
$$= 466.2\ gPM10.a^{-1}$$
$$= 3,605.1\ g\ NOx.a^{-1}$$
$$= 796.8\ gCO.a^{-1}$$

$$\mathbf{= 8,864.4\ g\ pollution.a^{-1}}$$

5.2.17 Energy Generation: Inhabitation

This criterion will consider the contribution that will be made to the reduction of pollution emissions if the energy demand of the dwelling were created from renewable sources as opposed to fossil fuels. If the area of the dwelling, based on typical occupancy figures is 59.8 m^2, then the overall reduction in fossil fuel consumption will be:

$$12 \times 59.8 = 717.6\ kWh.a^{-1}\ gas$$
$$13 \times 59.8 = 777.4\ kWh.a^{-1}\ electricity$$

The emissions of pollutants that are associated with the burning of these fuel types have been determined under the Energy Consumption: Inhabitation benchmark. Therefore, the emissions that would be created by these energy consumption values can be determined as:

Gas:

$$717.6 \times 0.008 = 5.74\ gSO_2.a^{-1}$$
$$717.6 \times 0.004 = 2.87\ gPM10.a^{-1}$$
$$717.6 \times 0.372 = 266.9\ g\ NOx.a^{-1}$$
$$717.6 \times 0.011 = 7.89\ gCO.a^{-1}$$

Electricity:	777.4 x 3.167	= 2,462.0 $gSO_2.a^{-1}$
	777.4 x 0.353	= 274.4 $gPM10.a^{-1}$
	777.4 x 0.903	= 702.0 $gNOx.a^{-1}$
	777.4 x 0.581	= 451.7 $gCO.a^{-1}$

Therefore in total the reduction in emissions that would be achieved by adopting the benchmark of Energy Consumption: Inhabitation will be:

= 2,467.7 $gSO_2.a^{-1}$

= 277.3 g $PM10.a^{-1}$

= 968.9 $gNOx.a^{-1}$

= 459.6 $gCO.a^{-1}$

= 4,165.8 g pollution.a^{-1}

5.2.18 Green Space

As was discussed under the Ecological Significance of the Site criterion, plants can also absorb forms of pollution. As different species have varying capabilities in the rate of absorption, and different rates of absorption for different pollutants for a given species, it would be difficult to attribute a quantitative value just on the basis of the quantity of green space provided, with no qualification as to the species within that green space.

5.2.19 Lifecycle cost

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.20 Nitrogen Oxide Emissions

The nitrogen oxide emissions from gas boilers benchmarked by the matrix are quantified under the generic term of NO_X emissions. The benchmark analysis proposed values for the NO_X emissions of both the 'typical' and the 'urban house in paradise', these two values are 153 and 60 $mg.kWh^{-1}$ respectively.

The relative contribution to the reduction of pollution that will be achieved through the benchmark of NO_X emissions will have to be calculated for equal levels of energy consumption. Otherwise this would, in effect, include the gains achieved by the reduction in energy consumption, which would mean that they would be double counted. The level of energy consumption that will be used will be that of the 'urban house in paradise', rather than that of the 'typical' dwelling. Whilst this might be considered as presupposing that the benchmark energy consumption of the 'urban house in paradise' will be met, it is intended that all of the benchmarks of the matrix will be achieved. If the consumption of the 'typical' dwelling were used to determine the emission level, then this would lead to a much higher level of emission than would occur for the 'urban house in paradise'. This may then lead to a higher priority weighting for NO_X emissions, which would present a distorted view of their overall significance.

The energy consumption for space and water heating, the functions usually served by gas boilers, is 12 $kWh.m^{-2}.a^{-1}$; the area of the dwelling, based on mean occupancy levels and the benchmarked space standards is $59.8m^2$. Therefore, the energy consumption is:

12.0 x 59.8 = 717.6 $kWh.a^{-1}$

Emissions arising from this level are:

'typical':	717.6 x 153	= 109.8 g $NO_X.a^{-1}$
'u h in p':	717.6 x 60	= 43.1 g $NO_X.a^{-1}$

Therefore the reduction in pollution emissions achieved by the benchmark reduction is:

109.8 – 43.1 **= 66.7 g pollution.a^{-1}**

5.2.21 Other Greenhouse Gas Emissions

Methane

The emission of methane has been considered under the parameter of Contribution to the Reduction of Global Warming. It will not be included here in order that it is not double counted.

CFCs

The emission of CFCs has been considered under the parameter of Contribution to the Reduction of Global Warming. It will not be included here in order that it is not double counted.

HCFCs

The emission of HCFCs has been considered under the parameter of Contribution to the Reduction of Global Warming. It will not be included here in order that it is not double counted.

Tropospheric Ozone

The emission of Tropospheric Ozone has been considered under the parameter of Contribution to the Reduction of Global Warming. It will not be included here in order that it is not double counted.

Nitrous Oxide

The emission of N_2O has been considered under the parameter of Contribution to the Reduction of Global Warming. It will not be included here in order that it is not double counted.

5.2.22 Other Ecological Impacts of Materials

The pollution that would arise as a consequence of the other ecological impacts of materials would be that other than from the fossil fuels consumed during extraction, processing and transport which is accounted for under the Ecological Weight: Embodied Energy criterion. The contribution of this criterion would be from wastage in these processes, if waste were considered as a form of pollution, and from emissions into the local environment from the extraction processes. However, data of the wastage rates of different materials per tonne of material extracted could not be determined, therefore the contribution to the reduction of pollution generated could not be determined.

5.2.23 Pollution: Energy Consumption Inhabitation

This benchmark is a measure of the level of pollution that is caused by the energy consumed during the period of inhabitation, measured on a relative scale, per kilowatt-hour. It is related to, but assessed independently, of the Energy Consumption: Inhabitation benchmark, and is intended to ensure that fuels are not used that cause higher levels of pollution when alternatives are available. As the benchmark is assessed independently of the level of energy consumption, the impact in terms of this parameter need not be considered in terms of both the level of energy consumption in the 'typical' dwelling and the 'urban house in paradise', but rather should be determined on the basis of only the latter.

Therefore, the energy consumption of the 'urban house in paradise', from the Energy Consumption: Inhabitation benchmark is:

$$25 \times 59.8 \qquad = 1495\ kWh.a^{-1}$$

As the impact of some of the pollution emissions under this benchmark will be considered under other parameters, namely those that contribute to the greenhouse effect and ozone depletion, the following table shows which are being considered here.

Dwelling	Pollutant Emissions (g.kWh^{-1} delivered)				
	SO_2	PM10	NOx	CO	**Total**
'Typical'	0.639	0.074	0.479	0.125	1.317
'u h in p'	0.320	0.038	0.240	0.063	0.661

Pollutant emissions per kWh for the typical dwelling and 'urban house in paradise'

The level of pollution arising from each benchmark can be determined as,

$$\text{Typical} = \quad 1.317 \times 1495 \quad = 1968.9\ g\ pollution.a^{-1}$$

$$\text{'u h in p'} = \quad 0.661 \times 1495 \quad = 988.2\ g\ pollution.a^{-1}$$

Therefore, the reduction in pollutant emissions that would be achieved by moving from the standard of the 'typical' dwelling to that of the 'urban house in paradise' is,

$$1968.9 - 988.2 \quad = \mathbf{970.7\ g\ pollution.a^{-1}}$$

5.2.24 Procurement strategy

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.25 Quality of Internal Environment: Indoor Pollution

In terms of its benchmark value, which has not been quantified in terms of the dimensional pollutant emissions but in terms of the materials specified within the dwelling, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.26 Quality of Internal Environment: Daylight

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.27 Quality of Internal Environment: Ventilation and Air Tightness

The Energy Consumption: Inhabitation criterion will determine the contribution made to the reduction in emissions through improvements in the efficiency of a number of factors that contribute to the overall energy consumption of the dwelling. However, reducing the heat loss that occurs through the ventilation rate and the air tightness of the dwelling's structure and fabric, as a contributor to this saving, will have a lesser impact upon reducing the energy consumption.

In order to determine the magnitude of these effects, the model of the 'urban house in paradise' that was developed for the Contribution to the Reduction of Natural Resources parameter, defined by a number of the benchmarks, will be used also. This will assist in the purposes of relative comparability of data. Two scenarios were taken, firstly of a dwelling with natural ventilation and an air tightness value both representative of a 'typical' dwelling, and secondly to the standards of the Quality of the Internal Environment: Ventilation and Air Tightness benchmark of the 'urban house in paradise'. The annual energy consumption was determined using the SAP model for both scenarios.

The reduction in energy consumption for space heating was determined as 1,966.7 $kWh.a^{-1}$. The increase in energy consumption as a result of the additional fans was determined as 59.8 $kWh.a^{-1}$. The emissions that will arise out of the reduction and consumption can be determined as:

Space heating (gas):	1,966.7 x 0.008	= 15.7$gSO_2.a^{-1}$
	1,966.7 x 0.004	= 7.87 $gPM10.a^{-1}$
	1,966.7 x 0.372	= 731.6 $g\ NOx.a^{-1}$
	1,966.7 x 0.011	= 21.6 $gCO.a^{-1}$

The additional energy consumption, that powers the fans, will be electrical:

Electricity:	59.8 x 3.167	= 189.4 $gSO_2.a^{-1}$
	59.8 x 0.353	= 21.1 $gPM10.a^{-1}$
	59.8 x 0.903	= 54.0 $g\ NOx.a^{-1}$
	59.8 x 0.581	= 34.7 $gCO.a^{-1}$

Therefore, the effect on pollution emissions due to the reduction in ventilation rate will be:

15.7 – 189.4	= -173.3 $gSO_2.a^{-1}$
7.87 – 21.1	= -13.2 $gPM10.a^{-1}$
731.6 – 54.0	= 677.6 g $NOx.a^{-1}$
21.6 – 34.7	= -13.1 $gCO.a^{-1}$

Therefore, the effect on pollution emissions created by achieving the Ventilation and Air Tightness benchmark of the 'urban house in paradise' will be:

-173.7 – 13.1 + 677.6 – 15.0	= **475.8 g pollution.a^{-1}**

This value must be treated with a degree of caution. As this criterion was concerned only with the direct effects of reducing the ventilation and infiltration rates, all other parameters were kept constant during the energy consumption modelling. Therefore no account is made of the consequent impacts of increasing the standard. All of these will be accounted for collectively by the Energy Consumption: Inhabitation criterion.

5.2.28 Recycling of Construction Waste

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.29 Recyclability of Building: Adaptability

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.30 Standards: Area

Increasing the space standards of the dwelling will have an impact on the overall pollution emissions of that dwelling, due to the increased energy consumption, which is benchmarked per unit area. For the average occupancy of dwellings in the United Kingdom, of 2.4, the Space Standards analysis gives a dwelling area of 48.5 m^2; for the 'urban house in paradise' this rises to 59.8 m^2, an increase of 11.3 m^2.

Therefore, the increase in pollutant emissions that will occur as a result of the average increase in Space standards will be:

Embodied energy:	(11.3 x 250) / 120	= 23.5 $kWh.a^{-1}$

Electricity:	7.85 x 3.167	= 24.9 $gSO_2.a^{-1}$
	7.85 x 0.353	= 2.77 $gPM10.a^{-1}$
	7.85 x 0.903	= 7.09 g $NOx.a^{-1}$
	7.85 x 0.581	= 4.56 $gCO.a^{-1}$
Gas:	7.85 x 0.008	= 0.06 $gSO_2.a^{-1}$
	7.85 x 0.004	= 0.03 $gPM10.a^{-1}$
	7.85 x 0.372	= 2.92 g $NOx.a^{-1}$
	7.85 x 0.011	= 0.09 $gCO.a^{-1}$
Petroleum	7.85 x 0.642	= 5.04 $gSO_2.a^{-1}$
	7.85 x 0.572	= 4.49 $gPM10.a^{-1}$
	7.85 x 5.894	= 46.3 g $NOx.a^{-1}$
	7.85 x 3.380	= 26.5 $gCO.a^{-1}$

Therefore, in total the additional embodied energy pollutant emissions will be:

= 30.0 $gSO_2.a^{-1}$

= 7.29 $gPM10.a^{-1}$

= 56.3 g $NOx.a^{-1}$

= 31.1 $gCO.a^{-1}$

During inhabitation:	11.3 x 15	= 169.5 kWh gas
	11.3 x 10	=113.0 kWh electricity

Gas:	169.5 x 0.008	= 1.36 $gSO_2.a^{-1}$
	169.5 x 0.004	= 0.68 $gPM10.a^{-1}$
	169.5 x 0.372	= 63.1 g $NOx.a^{-1}$
	169.5 x 0.011	= 1.86 $gCO.a^{-1}$
Electricity:	113.0 x 3.167	= 357.9 $gSO_2.a^{-1}$
	113.0 x 0.353	= 39.9 $gPM10.a^{-1}$
	113.0 x 0.903	= 102.0 $gNOx.a^{-1}$
	113.0 x 0.581	= 65.5 $gCO.a^{-1}$

Therefore, in total the additional pollutant emissions during inhabitation will be:

= 359.2 $gSO_2.a^{-1}$

= 40.6 $gPM10.a^{-1}$

= 165.1 g $NOx.a^{-1}$

= 67.4 $gCO.a^{-1}$

Thus, in total the additional emissions created by the additional energy consumption throughout the design life span of the dwelling due to the Space Standards: Area benchmark will be:

= 389.2 $gSO_2.a^{-1}$

= 47.9 $gPM10.a^{-1}$

= 221.4 g $NOx.a^{-1}$

= 98.5 $gCO.a^{-1}$

Therefore, in effect the contribution to the reduction of pollution is:

= - 757.0 g pollution.a^{-1}

5.2.31 Space Standards: Volume

Because the energy consumption both for both embodied energy and during the period of inhabitation is quantified by the benchmarks per unit area, the Space Standards: Volume criterion will have no additional effect. Therefore, in effect the contribution to the reduction of pollution is:

= - 757.0 g pollution.a^{-1}

5.2.32 Thermal Performance

The Energy Consumption: Inhabitation criterion will determine the contribution made to the reduction in pollution through improvements in the efficiency of a number of factors that contribute to the overall energy consumption of the dwelling. However, there will be a lesser benefit through solely increasing the thermal performance of the fabric of the dwelling; this value will also be affected by the increase in the embodied energy of the fabric.

In order to determine the magnitude of these effects, the model of the 'urban house in paradise' that was developed for the Contribution to the Reduction of Natural Resources parameter, defined by a number of the benchmarks, will be used also. This will assist in the purposes of relative comparability of data. Two scenarios were taken, firstly with the dwelling insulated to current Building Regulation standards, and secondly to the standards of the Thermal Performance benchmark of the 'urban house in paradise'. The annual energy consumption, determined using the SAP model for both scenarios, and the embodied energy of the additional insulation were calculated.

The reduction in energy consumption for space heating was determined as 569 kWh.a^{-1}. The increase in the embodied energy was determined as 5,395 kWh; spread across the design life span of the dwelling this equates to an annual equivalent value of 45.0 kWh.a^{-1}. The pollution that will arise out of the consumption can be determined as:

Space heating (gas):		569 x 0.008	= 4.56 $gSO_2.a^{-1}$
		569 x 0.004	= 2.28 $gPM10.a^{-1}$
		569 x 0.372	= 211.7 g $NOx.a^{-1}$
		569 x 0.011	= 6.26 $gCO.a^{-1}$
Embodied (1:1:1):			
	electricity:	15.0 x 3.167	= 47.5 $gSO_2.a^{-1}$
		15.0 x 0.353	= 5.30 $gPM10.a^{-1}$
		15.0 x 0.903	= 13.5 g $NOx.a^{-1}$
		15.0 x 0.581	= 8.72 $gCO.a^{-1}$
	gas:	15.0 x 0.008	= 0.12 $gSO_2.a^{-1}$
		15.0 x 0.004	= 0.06 $gPM10.a^{-1}$
		15.0 x 0.372	= 5.58 g $NOx.a^{-1}$
		15.0 x 0.011	= 0.17 $gCO.a^{-1}$
	petroleum	15.0 x 0.642	= 9.63 $gSO_2.a^{-1}$
		15.0 x 0.572	= 8.58 $gPM10.a^{-1}$
		15.0 x 5.894	= 88.4 g $NOx.a^{-1}$
		15.0 x 3.380	= 50.7 $gCO.a^{-1}$
			= 57.3 $gSO_2.a^{-1}$
			= 13.9 $gPM10.a^{-1}$
			= 107.3 g $NOx.a^{-1}$
			= 59.6 $gCO.a^{-1}$

Therefore, the reduction in pollution is:

4.56 – 57.3	= - 52.7 $gSO_2.a^{-1}$
2.28 – 13.9	= - 11.6 $gPM10.a^{-1}$
211.7 – 107.5	= 104.2 g $NOx.a^{-1}$

$6.26 - 59.7 \quad = -53.4\ gCO.a^{-1}$

$= -$ **13.5 g pollution.a**$^{-1}$

Thus whist there is an reduction in the energy consumption, because the space heating is gas fuelled, which has a relatively low pollution level, whereas the embodied energy has a mixture of fuel sources, the actual annual pollution is increased.

This value must be treated with a degree of caution. As this criterion was concerned only with the direct effects of increasing the thermal performance, all other parameters were kept constant during the energy consumption modelling. Therefore no account is made of the consequent impacts of increasing the standard, such as affects on the type of heating system that would be specified. All of these will be accounted for by the Energy Consumption: Inhabitation criterion.

5.2.33 Use of Recycled Materials

Whilst there will be an embodied energy consumption, and therefore consequent emission of pollutants, associated with the processing of recycled materials, the effect of this will be considered to be the equivalent of that consumed and emitted by the processing of virgin materials. Therefore, this will be accounted for within the Ecological Weight: Embodied Energy in Materials criterion.

5.2.34 Use of Renewable Raw Materials

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon on pollution emissions.

5.2.35 Utilisation of Local Resources

The only determinable effect that the utilisation of local resources may have on the reduction of pollution emissions will be through the reduction in transport. It has not been possible to determine the magnitude of total energy consumed through this criterion, and the mix of fuel types that would be used. Also, a benchmark for the typical dwelling could not be determined. Therefore it is not possible to establish the relative contribution of this criterion to the parameter of the reduction of pollution.

5.2.36 Water Consumption: Construction

From the benchmark analysis of this criterion, it was determined that the typical and 'urban house in paradise' benchmarks of water consumed during the construction of the dwelling are 34.1 and 8.5 litres per square metre. For the average occupancy of dwellings in the United Kingdom, of 2.4, the Space Standards analysis gives a typical dwelling area of 48.5 m^2; for the 'urban house in paradise' this rises to 59.8 m^2. Therefore, the quantity of water consumed in the construction of these two dwellings can be determined as,

48.5 x 34.1	= 1,653.8 litres
59.8 x 8.5	= 508.3 litres
∴ reduction	= 1,144.7 litres

Accounting for the life span of the dwelling, the annual equivalent reduction will be:

1,144.7 / 120	= 9.54 litres.a^{-1}

It was also determined that the reduction of 153.5 litres of potable water consumption per person per day will equate to an energy reduction of 0.08 kWh of energy per day. Therefore, the reduction of 9.54 litres per annum will equate to an energy reduction of 0.005 kWh.a^{-1}. The generation of that energy will create pollution. For the purposes of this calculation, it will be assumed that all of this energy will be electricity.

As for the other parameters, this energy is presumed to be all electricity. The pollution that is associated with the generation of this energy can be determined using the data in the criterion of Energy Consumption: Inhabitation:

0.005 x 3.167	= 0.0158gSO_2.a^{-1}
0.005 x 0.353	= 0.0012 gPM10.a^{-1}
0.005 x 0.903	= 0.0045gNOx.a^{-1}
0.005 x 0.581	= 0.0029 gCO.a^{-1}
	= 0.0244g pollution.a^{-1}

5.2.37 Water Consumption: Inhabitation

For the 'urban house in paradise' the level of mains consumption is benchmarked as 6.5 litres per person per day. During the analysis to determine the benchmark of Water Consumption: Inhabitation, it was determined that the reduction of 153.5 litres of potable water consumption per person per day will equate to an energy saving of 0.08 kWh of energy per day. Across the period of a year this will equate to an annual reduction of 29.2 kWh. Based on the mean occupancy figures for dwellings in the United Kingdom of 2.4 people per dwelling, this will equate to an annual household reduction of 70.1 kWh if the benchmark for the 'urban house in paradise' is achieved.

As for the other parameters, this energy is presumed to be all electricity. The pollution that is associated with the generation of this energy can be determined using the data in the criterion of Energy Consumption: Inhabitation:

$$70.1 \times 3.167 = 221.9\ gSO_2.a^{-1}$$

$$70.1 \times 0.353 = 24.7\ gPM10.a^{-1}$$

$$70.1 \times 0.903 = 63.3\ gNOx.a^{-1}$$

$$70.1 \times 0.581 = 40.7\ gCO.a^{-1}$$

$$\mathbf{= 350.6\ g\ pollution.a^{-1}}$$

A potential further contribution to the reduction of pollution by this criterion is the reduction of sewage discharged by the dwelling, both through the reduced water consumption and the potential use of composting toilets. However, within the scope of the work, data could not be determined to quantify the pollution discharged into the natural environment in proportion to the water discharged by the dwelling. Therefore these effects could not be accounted for within the analysis.

5.3 Prioritising – Contribution to a Reduction of Natural Resource Consumption

In order to prioritise the criteria against this parameter, a value is determined for each on the basis of the quantity of natural resource materials that will be saved by moving from the standards determined for the 'typical' dwelling to the benchmark values of the 'urban house in paradise'. The higher this value is, the greater the contribution being made, and therefore the higher the priority attributed to that criterion.

Wherever possible, the value determined is quantified in terms of either volume, as opposed to mass, or area of the resource being saved. This is for two reasons; firstly allows greater comparability between criteria that are determined by volume with those determined by area; secondly, quantifying by volume as opposed to mass gives a more true reflection of the quantity of resource being used. For example, for a substance with a very low density, such as rockwool, a large volume of material per kilogram would be extracted; where as for a higher density material, such as concrete, a much lower volume would be extracted per kilogram. Using volume as a unit of measurement provides a more comparable measure of the amount of resource that is being saved for differing materials.

5.3.1 CO_2 Emissions: construction and deconstruction

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.2 CO_2 Emissions: Inhabitation

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.3 Carbon Intensity

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources. The consumption of natural resources by space and water heating will be accounted for under Energy Use: Inhabitation.

5.3.4 Construction Period

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.5 Contextual Significance of the Site

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.6 Deconstruction and Demolition: Recycling of Materials

The contribution given to the reduction of natural resource consumption by the recycling of deconstruction and demolition material, like the recycling of domestic waste, is based on the premise that recycling materials will prevent an equal quantity of virgin materials being extracted from natural sources. The benchmark level of the recycling of deconstruction and demolition material has been established as 85 percent. To translate this into a quantified value of materials that are recycled, and therefore natural resources saved, will require determining a value for the quantity of material that might be used to construct the 'urban house in paradise'. The decision was taken to base the prioritising on the quantity of materials used to construct the 'urban house in paradise' rather than a typical dwelling. This was on the basis that if all of the benchmark standards are achieved, which would be an ideal condition, and the quantity of materials was based on the specification of the typical dwelling, it would not be a true reflection of the position of this criterion in the overall priority rating.

Determining a value for the quantity of materials was achieved through creating a model of the 'urban house in paradise' on the basis of a number of the benchmarks. As the prioritising process is a relative comparison between the criteria, standards and quantities that have been used for other criteria and other parameters will also be used here to achieve a level of consistency in the process. The size of the dwelling, in terms of area and volume, will be based on the Space Standards benchmark for the mean occupancy level given by census data of 2.4 people per dwelling; it will be 59.8 m^2 with a floor to ceiling height of 3 m. The dwelling type, a flat within a four storey terraced block, was based on a type appropriate to both the occupancy level and the density benchmark of 370 people per hectare. The glazed area was based on the Quality of Internal Environment: Daylight benchmark; and the level of insulation was based on the Thermal Performance benchmark. The materials used to create the foundations, roof and party walls will be divided between the appropriate dwellings. The construction technology was based on relatively traditional methods of brick and block walls to the external facades, block party walls, concrete ground floor, timber intermediate floors and timber internal partitions. Triple glazing was assumed, in order to achieve the Thermal Performance benchmark. The depth of analysis has been set at the volume and mass of principal materials (such as brick and timber but not cavity ties and nails) used to construct the shell and interior floors and partitions of the dwelling. The volume for each material was established from the dimensions of the dwelling and material thickness, and the mass derived from density figures.[1] The results of the analysis are as follows:

Element	Material	Volume (m^3)
Foundations	Concrete	1.17
	Brick	1.17
	Insulation	0.83
Ground floor	Concrete	2.24
	Screed	0.38
	Insulation	2.54
	Hardcore	1.87
External walls	Brick	3.29
	Insulation	7.82
	Concrete block	3.13
	Plaster	0.35
Windows	Glass	0.071
Party walls	Concrete block	6.25
	Insulation	3.13
	Plaster	0.70
Internal floor	Timber	3.32
	Plaster	0.72
Internal partitions	Plaster/board	1.98
	Timber	0.99
Roof	Concrete	0.66
	Felt	0.03
	Timber	0.43
	Insulation	8.07
	Concrete block	2.01
	Plaster/board	0.26

Therefore, in total the materials used to construct the 'urban house in paradise are summarised in the following table.

[1] Thomas, Randall (ed). *Environmental Design – An Introduction for Architects and Engineers*, London: E & F N Spon, 1996.

Material	Volume of materials in dwelling (m^3)
Insulation	22.39
Concrete block	11.39
Timber	4.46
Concrete	4.07
Plaster/board	4.01
Hardcore	1.87
Screed	0.38
Glass	0.071
Felt	0.03
Total	53.41

Volume of materials used in the construction of the dwelling

Therefore, if the benchmark for the recycling of deconstruction and demolition materials has been established as 85 percent, this will equate to a reduction in the consumption of natural resources of:

$$53.41 \times 0.85 \qquad = 45.40$$

Spread across the life span of the dwelling, in order to determine an equivalent value of the natural resources that would be saved each year would be:

$$45.40 / 120 \qquad = \mathbf{0.38\ m^3.a^{-1}}$$

When the materials used to construct the dwelling are extracted an area of land will also be lost, in addition to the material itself; for example, the provision of timber will cause both the loss of an individual tree and the destruction of the forest. Land itself is a resource and therefore the area of land saved can be added to the contribution made to reducing natural resource consumption by the recycling of demolition materials. This is not double counting because both the material and the area of land would be lost, and both are resources, the land not least because of its provision of habitat.

Environmental footprinting software can provide data for the area of land that is consumed by the provision of some building materials.[2] These are summarised in the following table.

2 Values are taken from environmental footprint database produced by Best Foot Forward, Oxford.

Material	Land area (ha.tonne^{-1})
Concrete	9.49049×10^{-6}
Wood: UK softwood	0.20205519
Wood: UK chipboard	0.20205519
Wood: Imported softwood (European	0.20205519
Wood: Imported softwood (global)	0.656345132
Wood: Tropical hardwood	3.623188406
Sand and gravel	9.49049×10^{-6}
Steel	5.0×10^{-6}

Area of land associated with the production of construction materials

These values can be used to translate the quantity of materials, converting the volume into mass using standard density values, recycled in the demolition of the 'urban house in paradise', determined in the analysis above, into the land area saved through their recycling.

Mass of concrete recycled:

$0.85 \times (11.39 \times 1200)$ = 11,617.8 kg

area of land:

$11.62 \times 9.49049 \times 10^{-6}$ = 0.00011 ha

Mass of timber recycled:

$0.85 \times (4.79 \times 700)$ = 2,820.3 kg

area of land:

2.82×0.20205519 = 0.570 ha

Mass of hardcore recycled:

$0.85 \times (1.87 \times 1500)$ = 2,384.3 kg

area of land:

$2.38 \times 9.49049 \times 10^{-6}$ = 0.0000226 ha

The total area of land saved, spread across the life span of the dwelling:

$(0.00011 + 0.570 + 0.0000226) / 120$ = 0.00475 ha.a^{-1}

= **47.5 m^2.a^{-1}**

5.3.7 Design Life Span

The benchmark of design life span of the dwelling will have an effect on reducing the consumption of natural resources. For example, extending the life of the dwelling will make more efficient use of the materials that are embodied within it and any wastes generated during its construction. However, for the materials that are from reused or recycled sources, it will be inconsequential as to how long they are embodied within the fabric of the dwelling. The contribution of the design life span benchmark to the reduction of natural resource consumption will be the cumulative effect of increasing the design life span of the dwelling by 60 years. To determine this, each criterion, where applicable, will be taken individually and then the contributions all summed.

Deconstruction and Demolition: Recycling of Materials

For the materials that are recycled when the dwelling is demolished, it is inconsequential as to how long they have been embodied within the fabric of the dwelling; however prolonging the life span of the dwelling will make more efficient use of the materials within it that are not recycled when it is deconstructed. As the level of recycled materials from this process is benchmarked at 85 percent, the life span of the dwelling will have an impact on 15 percent of the materials used to construct the dwelling. From the model analysis used for the prioritising process, the volume of material used to construct an 'urban house in paradise' was 53.41 m^3, refer to Deconstruction and Demolition: Recycling of Materials criterion above. Therefore, the 15 percent of those materials that will not be recycled is 8.01 m^3. Therefore, the effect of the design life span benchmark will be:

$$8.01 / 60 = 0.13$$
$$8.01 / 120 = 0.07$$
$$\therefore \text{effect of life span} = 0.06\ m^3.a^{-1}$$

As in the analysis of the Deconstruction/demolition: recycling of materials above, there will be a contribution to the reduction of land consumption through extending the life span of the 15 percent of materials that are not recycled. 15 percent of 47.5 is 7.125.[3]

$$7.125 / 60 = 0.119$$
$$7.125 / 120 = 0.059$$
$$\therefore \text{effect of life span} = 0.06\ m^3.a^{-1}$$

[3] This is the value of land saved through the recycling of 85 percent of the materials in the dwelling on its demolition.

Ecological Weight: Embodied Energy

On the basis of the average occupancy level and the Space Standards: Area benchmark, the embodied energy for the 'urban house in paradise' is 59.8 x 250 = 14,950 kWh. Therefore, the effect of the life span benchmark will be:

	14,950 / 60	= 249.2 $kWh.a^{-1}$
	14,950 / 120	= 124.6 $kWh.a^{-1}$
	∴ effect of life span	= 124.6 $kWh.a^{-1}$

The natural resource consumption associated with this reduction is:

Electricity:	41.5 x 0.14	= 5.81 kg $coal.a^{-1}$
	41.5 x 0.06	= 2.49 kg natural $gas.a^{-1}$
	41.5 x 0.01	= 0.42 kg $petroleum.a^{-1}$
Gas:	41.5 x 0.12	= 4.98 kg natural $gas.a^{-1}$
Petroleum:	41.5 x 0.13	= 5.40 kg $petroleum.a^{-1}$

Therefore, the total reduction in natural resources will be:

= 5.81 kg $coal.a^{-1}$

= 7.47 kg natural $gas.a^{-1}$

= 5.82 kg $petroleum.a^{-1}$

Using the densities of these fuels, these values can be converted into the volume of natural resources that will be saved:

5.81 / 1500	= 0.004 m^3 $coal.a^{-1}$
7.47 / 0.67	= 11.1 m^3 natural $gas.a^{-1}$
5.82 / 800	= 0.007 m^3 $petroleum.a^{-1}$

=11.1 m^3 natural $resource.a^{-1}$

Energy Consumption: Construction Processes

The pollution emissions created by these processes will be included within the overall calculation of the Ecological Weight: Embodied Energy criterion, and therefore should not be included here so that its effect is not double counted when the cumulative total is determined.

Reduction of Construction Waste

The material that arises as construction waste will be just as much a natural resource use as the same amount of material embodied within the dwelling itself. The volume of waste arising from the construction of the model analysis of the 'urban house in paradise' has been determined as 1.34 m^3. However, from the Use of Recycled Materials criterion, it can be determined that only 24 percent of this value will be natural resources, as the remainder will be derived from recycled sources. Therefore, the impact of spreading this waste over the longer design life span of the 'urban house in paradise' will be:

0.32 / 60	= 0.005 $m^3.a^{-1}$
0.32 / 120	= 0.003 $m^3.a^{-1}$
∴ effect of life span	= 0.002 $m^3.a^{-1}$

Space Standards: Area and Volume

The additional materials used to create the larger dwelling benchmarked by the Space Standards: Area and Volume criteria are accounted for in the analysis of the effect of the design life span on the criterion of Use of Recycled Materials; to include the impact here also would be double count the effect upon natural resource consumption.

Thermal Performance

The impact in terms of the embodied energy of increasing the level of thermal performance of the dwelling's fabric will be accounted for within the Ecological Weight: Embodied Energy criterion, and will not be assessed here so as no to double count when calculating the cumulative effect. As the benchmark for Use of Recycled materials requires that 100 percent of insulation material be derived from recycled sources, there will be no additional effect on natural resource consumption from the material requirements.

Use of Recycled Materials

The length of the life span, in terms of the consumption of natural resources, will only be of a consequence to the materials that are not from reused or recycled sources. In terms of the model analysis conducted for this criterion below, this will be 8.0 m^3. Therefore, the effect of the prolonged design life span will be:

8.0 / 60	= 0.13 $m^3.a^{-1}$
8.0 / 120	= 0.07 $m^3.a^{-1}$

$\therefore$ effect of life span $= 0.063\ m^3.a^{-1}$

Therefore, in total the reduction in natural resource consumption achieved through increasing the design life span of the dwelling to the benchmark of the 'urban house in paradise' will be:

$$0.06 + 0.60 + 11.1 + 0.002 + 0.0063 \quad = \mathbf{11.3\ m^3.a^{-1}}$$

5.3.8 Density: Quantitative

The typical value of residential density determined by the analysis of the benchmark values is 100 people per hectare; for the 'urban house in paradise' the minimum value of residential density has been determined as 370 people per hectare.

Therefore, the base density for the 'urban house in paradise' is three times higher than that of the typical dwelling; thus it will, in effect, occupy three times less footprint space than the typical dwelling. Using the typical occupancy level of dwellings of 2.4 people, for the purposes of a relative comparison, 370 people per hectare equates to 154 dwellings per hectare. At this density, in effect, 64 m^2 of land will be accounted for by each dwelling; the same number of dwellings at the typical residential density would occupy three times the area. Land is a primary resource, and its use has implications, in anthropocentric terms, for material and energy use, and in Deep Ecological terms for biodiversity and hydrology.[4] Therefore, the land saved by moving from the benchmark of the typical residential density to that of the 'urban house in paradise' will be 160 m^2, or divided across the life span of the dwelling:

$$176 / 120 \quad = \mathbf{1.47\ m^2.a^{-1}}$$

5.3.9 Density: Qualitative

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.10 Diversity: Programme

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.11 Domestic Waste

By providing materials that have been recycled from domestic waste, there will be a reduction in the primary use of natural resources that would have otherwise have been used in the manufacturing of products and goods. The level of that saving will be dependant upon the potentially recyclable content of that waste. The typical breakdown of domestic refuse was determined under the Domestic Waste benchmark, and is summarised in the following table.

Material	Recyclable material, kg and m³ per person per week		
	Mass	Recyclable mass	Recyclable volume
Paper and card	3.0	3.0	0.0046
Plastic film	0.5	-	-
Dense plastic	0.5	0.5	0.00052
Textiles	0.2	0.2	0.0004
Misc combustibles	0.7	-	-
Misc non-combustibles	0.2	-	-
Glass	0.8	0.8	0.00032
Putrescibles	1.9	-	-
Ferrous metals	0.5	0.5	0.00006
Non-ferrous metals	0.1	0.1	0.00004
< 10mm fines	0.8	-	-
Total	9.3	5.1	**0.0059**

Recyclable material, kg and m³ per person per week, of domestic refuse

In terms of mass, this equates to a reduction of natural resource consumption, through recycling of waste materials, of 0.0059 m³ per person per week. At a mean occupancy, this is 0.014 m³ per dwelling per week; therefore the contribution made by the dwelling annually will be,

$$= \mathbf{0.74\ m^3.a^{-1}}$$

[4] Personal communication form Professor John Whitelegg, Professor of Environmental Studies, Liverpool John Moores University, 7 November 1999.

5.3.12 Ecological Significance of the Site

Through the benchmark that 100 percent of the land used for the site of the 'urban house in paradise' should be brownfield land, this will make a contribution to the reduction in the consumption of natural resources, on the basis that green land is a natural resource. The current level of brownfield land use for residential development is approximately 47 percent.[5] From the Density: Quantitative benchmark, it has been determined that at the average occupancy level of 2.4 people per dwelling, in effect, 64 m^2 of land will be accounted for by each dwelling. Spread across the design life span of the dwelling, this equate to a reduction in the consumption of natural resources of:

64 / 120 = 0.533 $m^2.a^{-1}$

Taking account of the existing 47 percent of land use that is brownfield:

0.53 - (0.53 x 0.47) **= 0.28 $m^2.a^{-1}$**

5.3.13 Ecological Weight: Embodied Energy

The benchmark analysis can be used to determine comparable embodied energy values for a 'typical' dwelling and an 'urban house in paradise' based on the Space Standards: Area benchmark, using the average occupancy level from census data, and the Ecological Weight: Embodied Energy benchmark:

'typical' =	1,000 x 48.5	= 48,500 kWh
'urban house in paradise' =	250 x 59.8	= 14,950 kWh
∴ reduction =	48,500 – 14,950	= 33,550 kWh

Across the life span of the dwelling, this is the equivalent annual reduction of:

33,500 / 120 = 279.2 $kWh.a^{-1}$

Assuming a 1:1:1 ratio for the mixture of electricity : gas : petroleum for fuel types used during the period of embodied energy consumption gives a value per fuel type of 93.1 $kWh.a^{-1}$.

5 Derived from Land Use Change Statistics in: Urban Task Force. *Towards an Urban Renaissance*, London: E & F N Spon, 1999.

Depending upon their calorific value, different fuels produce different quantities of energy per unit of mass. Also, the various methods used to produce energy have different efficiencies; this, in addition to the effects of transmission in the case of electricity, will affect the amount of delivered energy that can be derived from each kilogram of raw fuel.

The calorific values of the common domestic fuels[6] can be used to derive the quantity of those fuels need to provide equal units of power. These were determined as coal= 0.12 kg.kWh-1, gas= 0.08 kg.kWh-1, and oil= 0.07 $kg.kWh^{-1}$. However, these values represent the theoretical maximum that could be extracted; in reality, due to inefficiencies in the process of conversion, the mass required will be greater.

Thomas proposes that the inefficiencies between the potential energy and the end user efficiency will mean that the actual consumption for natural gas will be 0.12 $kg.kWh^{-1}$.[7] The 1998 *Digest of United Kingdom Energy Statistics* proposes figures for the quantities of fuel used in the generation of electricity;[8] these are 0.43 kg coal and 0.25 kg petroleum (including oil) per kWh. Assuming the efficiency of modern gas fired power stations to be 40 percent, the consumption of gas to produce electricity will be 0.19 $kg.kWh^{-1}$. The *Digest* also provides the breakdown of fuel types used in the generation of electricity, on the basis of output; this is 33 percent coal, 31 percent gas, 26 percent nuclear and 2 percent oil. From this breakdown it can be approximated that to produce 1 kWh of electricity the generation will consume 0.14 kg coal, 0.06 kg gas, and 0.01 kg petroleum.

The quantity of fuel that would have been used to generate this embodied energy saving can now be determined:

Electricity:	93.1 x 0.14	= 13.0 kg $coal.a^{-1}$
	93.1 x 0.06	= 5.58 kg natural $gas.a^{-1}$
	93.1 x 0.01	= 0.93 kg $petroleum.a^{-1}$
Gas:	93.1 x 0.12	= 11.2 kg natural $gas.a^{-1}$
Petroleum:	93.1 x 0.13	= 12.1 kg $petroleum.a^{-1}$

---

[6] Shorrock, L. D. and G. Henderson. *Energy Use in Buildings and Carbon Dioxide Emissions*, Building Research Establishment, 1990 and, Thomas, Randall. *Environmental Design*, London: E & F N Spon, 1996. The calorific values were determined from these sources to be: coal = 30 $MJ.kg^{-1}$, gas = 47.3 $MJ.kg^{-1}$, and oil = 51.4 $MJ.kg^{-1}$.

[7] Thomas, Randall. Op. Cit.

[8] Department of Trade and Industry. *Digest of United Kingdom Energy Statistics 1998*, London: HMSO, 1998.

Therefore, the total reduction in natural resources will be:

= 13.0 kg coal.a^{-1}

= 16.8 kg natural gas.a^{-1}

= 13.0 kg petroleum.a^{-1}

Using the densities of these fuels, these values can be converted into the volume of natural resources that will be saved:

13.0 / 1500	= 0.01 m^3 coal.a^{-1}
16.8 / 0.67	= 25.1 m^3 natural gas.a^{-1}
13.0 / 800	= 0.02 m^3 petroleum.a^{-1}

In total, the reduction in natural resource consumption will be:

0.01 + 25.1 + 0.02 = **25.13 m^3.a^{-1}**

5.3.14 Ecological Weight: Embodied CO_2 Emission

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.15 Energy Consumption: Construction Processes

As for the other criteria that benchmark a reduction in the consumption of fossil fuel, there will also be a reduction in other pollutants. The reduction in energy consumption during on site construction can be determined from the benchmark analysis. From the mean occupancy value, Space Standards: Area and Energy Consumption: Construction Processes benchmarks, the reduction in energy consumption can be determined as:

'typical':	150 x 48.5	= 7,275 kWh
'urban house in paradise'	75 x 59.8	= 4,485 kWh
∴ reduction =	7,275 – 4,485	= 2,790 kWh

Across the design life span of the dwelling, this will equate to an annual equivalent reduction of:

2,790 / 120 = 23.3 kWh.a^{-1}

In terms of fuel mix, gas will not be used as much for a fuel source during on site construction, and therefore the ratio has been proposed as 4.5:4.5:1 for electricity : petroleum : gas.

The quantity of fuel that would have been used to generate the energy saving can now be determined:

Electricity:	10.5 x 0.14	= 1.46 kg coal.a^{-1}
	10.5 x 0.06	= 0.63 kg natural gas.a^{-1}
	10.5 x 0.01	= 0.10 kg petroleum.a^{-1}
Gas:	2.32 x 0.12	= 0.28 kg natural gas.a^{-1}
Petroleum:	10.5 x 0.13	= 1.36 kg petroleum.a^{-1}

Therefore, the total reduction in natural resources will be:

= 1.46 kg coal.a^{-1}

= 0.91 kg natural gas.a^{-1}

= 1.46 kg petroleum.a^{-1}

Using the densities of these fuels, these values can be converted into the volume of natural resources that will be saved:

1.46 / 1500	= 0.001 m^3 coal.a^{-1}
0.91 / 0.67	= 1.36 m^3 natural gas.a^{-1}
1.46 / 800	= 0.002 m^3 petroleum.a^{-1}

In total, the reduction in natural resource consumption will be:

0.001 + 1.36 + 0.002 **= 1.363 m^3.a^{-1}**

5.3.16 Energy Consumption: Inhabitation

Depending upon their calorific value, different fuels produce different quantities of energy per unit of mass. Also, the various methods used to produce energy have different efficiencies; this, in addition to the effects of transmission in the case of electricity, will affect the amount of delivered energy that can be derived from each kilogram of raw fuel.

The quantity of fuel that is required to provide the energy needs by different sources has been determined under the criterion of Ecological Weight: Embodied Energy. These values can also be used here to determine the quantities of fuel, and therefore resource, that will be saved by moving from the energy consumption of the typical dwelling to the energy consumption of the 'urban house in paradise'. Using the dwelling area proposed by the Space Standards benchmark for the mean occupancy of dwelling, of 48.5 m^2 for the typical dwelling and 59.8 m² for the 'urban house in paradise' will give the following consumption values:

Function	Energy (kWh per annum)		
	'Typical'	U H in P	Reduction
Space heating	4,559	717.6	6,460.4
Hot water	2,619	Included above	Included above
Pumps and fans	97	179.4	-82.4
Cooking	388	179.4	208.6
Lights and appliances	1,746	418.6	1,327.4

Reduction in energy consumption: inhabitation between typical dwelling and urban house in paradise

Assuming the same mix of fuel types for both dwellings, and that both will use non-renewable sources of fuel the reduction in fuel consumption between the two benchmarks will be 6,669 kWh of gas and 1,245 kWh of electricity. The additional reduction achieved by using renewable sources of fuel is determined under the Energy Generation criterion below.

The amount of fuel that would have been used to generate this energy saving can now be determined:

reduction of 6,669 kWh natural gas = 6,669 x 0.12 = 800.3 kg natural gas

reduction of 1,245 kWh electricity = 1,245 x 0.14 = 174.3 kg coal
1,245 x 0.06 = 74.7 kg natural gas
1,245 x 0.01 = 12.5 kg petroleum

Therefore, the total reduction in the consumption of natural resources achieved by moving between the standard of the typical dwelling and the 'urban house in paradise' will be:

= 174.3 kg coal.a^{-1}

= 875 kg natural gas.a^{-1}

= 12.5 kg petroleum.a^{-1}

For comparability with the other criteria within this parameter, these figures can be converted into volumetric values from the density of each fuel:

174.3 / 1500 = 0.12 m³ coal.a^{-1}

875 / 0.67 = 1,306.0 m³ natural gas.a^{-1}

12.5 / 800 = 0.02 m³ petroleum.a^{-1}

In total, the reduction in natural resource consumption will be:

0.12 + 1,306.0 + 0.02 **= 1,306.1 m³/a**

5.3.17 Energy Generation: Inhabitation

Through the use of renewable sources of energy to fulfil the demands of the 'urban house in paradise', the consumption of fossil fuels can be completely eradicated. If the area of the dwelling, based on typical occupancy figures is 59.8 m^2, then the overall reduction in fossil fuel consumption will be:

12 x 59.8 = 717.6 $kWh.a^{-1}$gas

13 x 59.8 = 777.4 $kWh.a^{-1}$ electricity

The Energy Consumption: Inhabitation criterion determined the quantity of fuel that is consumed in the provision of electrical energy. Therefore, these figures can be used to determine the resources that will be saved through providing the electrical energy needs through renewable sources:

777.4 x 0.14 = 108.8 kg $coal.a^{-1}$

777.4 x 0.06 = 46.6 kg natural $gas.a^{-1}$

777.4 x 0.01 = 7.8 kg $petroleum.a^{-1}$

Again, using the data determined within the Energy Consumption: Inhabitation criterion above, the fuel that would be saved by using renewable sources to provide the energy needs that would otherwise be provided by gas is:

717.6 x 0.12 = 86.1 kg natural $gas.a^{-1}$

Therefore in total the contribution in the reduction of fossil fuel consumption of the Energy Generation: Inhabitation benchmark will be:

108.8 kg $coal.a^{-1}$

132.7 kg natural $gas.a^{-1}$

7.8 kg $petroleum.a^{-1}$

For comparability with the other criteria within this parameter, these figures can be converted into volumetric values from the density of each fuel:

108.8 / 1500 = 0.07 m^3 $coal.a^{-1}$

132.7 / 0.67 = 198.1 m^3 natural $gas.a^{-1}$

$$7.8 / 800 \quad = 0.01\ m^3\ \text{petroleum}.a^{-1}$$

In total, the reduction in natural resource consumption will be:

$$0.07 + 198.1 + 0.01 \quad = \mathbf{198.2\ m^3.a^{-1}}$$

5.3.18 Green Space

In terms of its benchmark value, this criterion could be considered to have a measurable consequential effect on the depletion of natural resources. However, as the thesis is predicated on urban dwelling, the change in the provision of green space between that of the typical dwelling, and that of the 'urban house in paradise' is in fact a decrease. The benchmark of the typical national house builder was established as 196 percent, and that of the 'urban house in paradise' of 25 percent. In a dwelling with a typical occupancy of 2.4 people, with a benchmarked floor area of 59.8 m^2, these two values will equate to 117.2 m^2 and 14.95 m^2. Therefore the change in resource use is determined as:

$$117.2 - 14.95 \quad = 102.3\ m^2$$

Accounting for the design life span of the dwelling, of 120 years, this reduction can be translated into a value in terms of a factor per annum of:

$$102.3 / 120 \quad = \mathbf{0.85\ m^2.a^{-1}}$$

5.3.19 Lifecycle cost

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.20 Nitrogen Oxide Emissions

The nitrogen oxide emitted from the combustion process will be included within the fuel consumption, determined under Energy Consumption: Inhabitation criterion. It is an output rather than a resource that is consumed.

5.3.21 Other Greenhouse Gas Emissions

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.22 Procurement strategy

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.23 Other Ecological Impacts of Materials

In terms of its benchmark value, this criterion is considered to have no direct and measurable consequential reduction upon the depletion of natural resources.

5.3.24 Quality of Internal Environment: Indoor Pollution

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources.

5.3.25 Quality of Internal Environment: Daylight

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the depletion of natural resources. Any benefits gained through the reduction in artificial light will be accounted for within the Energy Consumption: Inhabitation criterion.

5.3.26 Quality of Internal Environment: Ventilation and Air Tightness

The Energy Consumption: Inhabitation criterion will determine the contribution made to the reduction in emissions through improvements in the efficiency of a number of factors that contribute to the overall energy consumption of the dwelling. However, reducing the heat loss that occurs through the ventilation rate and the air tightness of the dwelling's structure and fabric as a contributor to this saving will have a lesser impact upon reducing the energy consumption.

In order to determine the magnitude of these effects, the model of the 'urban house in paradise' that was developed for this parameter under the Deconstruction and Demolition: Recycling of Materials criterion, defined by a number of the benchmarks, will be used also. This will assist in the purposes of relative comparability of data. Two scenarios were taken, firstly of a dwelling with natural ventilation and an air tightness value both representative of a 'typical' dwelling, and secondly to the standards of the Quality of the Internal Environment: Ventilation and Air Tightness benchmark of the 'urban house in paradise'. The annual energy consumption was determined using the SAP model for both scenarios.

The reduction in energy consumption for space heating was determined as 1,966.7 kWh.a^{-1}. The increase in energy consumption as a result of the additional fans was determined as 59.8 kWh.a^{-1}. The natural resource depletion that will arise out of the reduction and consumption can be determined as:

Space heating (gas): 1,966.7 x 0.12 = 236.0 kg natural gas.a^{-1}

Using the densities of this fuel, this value can be converted into the volume of natural resources that will be saved:

236.0 / 0.67 = 352.2 m^3 natural gas.a^{-1}

The additional energy consumption, that powers the fans, will be electrical:

Electricity:	59.8 x 0.14	= 8.37 kg coal.a^{-1}
	59.8 x 0.06	= 3.59 kg natural gas.a^{-1}
	59.8 x 0.01	= 0.60 kg petroleum.a^{-1}

Using the densities of the fuels, these values can be converted into the volume of natural resources that will be saved:

8.37 / 1500	= 0.006 m^3 coal.a^{-1}
3.59 / 0.67	= 5.70 m^3 natural gas.a^{-1}
0.60 / 800	= 0.001 m^3 petroleum.a^{-1}
	= 5.71 m^3 natural resources.a^{-1}

Therefore, the effect on resource depletion created by achieving the Ventilation and Air Tightness benchmark of the 'urban house in paradise' will be:

352.2 – 5.71 = **346.5 m^3.a^{-1}**

This value must be treated with a degree of caution. As this criterion was concerned only with the direct effects of reducing the ventilation and infiltration rates, all other parameters were kept constant during the energy consumption modelling. Therefore no account is made of the consequent impacts of increasing the standard. These will collectively be accounted for by the Energy Consumption: Inhabitation criterion.

5.3.27 Reduction and Recycling of Construction Waste

From the benchmark analysis it has been determined that the typical level of construction waste is 10 percent of materials within the buildings, and the benchmark for the 'urban house in paradise' has been set at 2.5 percent. Therefore, this will be the reduction in consumption of a natural resource, as waste is an extracted material that is not put to any use, but is in effect still consumed.

The quantity of material used to translate this percentage into a quantitative value will be value determined under the Deconstruction and Demolition: Recycling of Materials criterion of the quantity of material used to construct an 'urban house in paradise'; this is to ensure consistency and comparability between the criteria. This value was 53.41 m^3. It should be noted that this value is of the primary bulk materials, and does not include plumbing and electrical materials and second fix timber.

The values of waste can be determined as:

'typical' dwelling = 53.41 x 0.1 = 5.34

'urban house in paradise' = 53.41 x 0.025 = 1.34

Therefore, the reduction made by achieving the benchmark will be:

5.34 – 1.34 = 4.01 m^3

Over the design life span of the dwelling, this will equate to an equivalent annual reduction of:

4.01 / 120 = **0.03 $m^3.a^{-1}$**

As for the recycling of demolition materials, the reduction of construction waste material will also mean a reduction in the area of land from which the material would have been sourced. The model dwelling used in the analysis above can also be used here.

Mass of concrete:

	0.1 x (11.39 x 1200)	= 1,366.8 kg
	0.025 x (11.39 x 1200)	= 341.7 kg
reduction =	1,366.8 - 341.7	= 1,025.1 kg

area of land:

1.025x 9.49049 x 10^{-6} = 0.00001 ha

Mass of timber:

0.1 x (4.79 x 700) = 335.3 kg

0.025 x (4.79 x 700) = 83.8 kg

reduction = 335.3 – 83.8 = 251.8 kg

area of land:

0.252 x 0.20205519 = 0.051 ha

Mass of hardcore:

0.1 x (1.87 x 1500) = 280.5 kg

0.025 x (1.87 x 1500) = 70.1 kg

reduction = 280.5 – 70.1 = 210.4 kg

area of land:

$0.21 \times 9.49049 \times 10^{-6}$ = 0.000002 ha

The total area of land saved, spread across the life span of the dwelling:

(0.00001 + 0.051 + 0.000002) / 120 = $0.00042\ ha.a^{-1}$

= $\mathbf{4.23\ m^2.a^{-1}}$

5.3.28 Recyclability of Building: Adaptability

The ability of the dwelling to adapt to changing needs or even change of use will be a part of the way in which an increase in the design life span of the 'urban house in paradise' can be achieved. Therefore, on its own this criterion is considered to have no directly consequential effect on the reduction of the depletion of natural resources.

5.3.29 Space Standards: Area

The benchmark increase in the area of the dwelling will have an impact on the quantity of materials that are required to construct it. The exact relationship between the increase in the size of the dwelling and the consequent increase in materials will be dependent upon the design of the dwelling, in terms of the perimeter to area ratio.

The methodology that was used to determine the quantity of materials in the 'urban house in paradise' for the Deconstruction and Demolition: Recycling of Materials criterion will also be used here in order to determine the extent of the impact of this criterion and benchmark on the consumption of resources. Two values will be derived, one based on the area of the 'typical' dwelling, and one for the area given by the benchmark by using the model dwelling from the Deconstruction and Demolition: Recycling of Materials criterion, but varying the floor area. Both will be based on the mean occupancy figure of 2.4 people per dwelling. This creates a 'typical' dwelling of 48.5 m^2, at 5.51 by 8.80 m, and an 'urban house in paradise' of 59.8 m^2, at 6.12 by 9.77 m; both are assumed to have an equal ceiling height of 2.3 m. The analysis will account for the raw material use only, and discard the recycled material content.

The algorithms used produce the following values:

Material	Volume of Material (m^3)		
	'Typical'	'u h in p'	Increase (inc recvc'd mats)
Insulation	16.21	19.63	0.0
Concrete block	6.81	9.20	0.60
Timber	3.96	4.57	0.46
Brick	3.18	3.59	0.10
Concrete	3.42	4.07	0.13
Plaster/board	3.11	3.29	0.18
Hardcore	1.52	1.87	0.0
Screed	0.30	0.38	0.08
Glass	0.67	0.07	0.03
Felt	0.23	0.30	0.07
Total	39.41	46.7	2.55

Increase in material use due to space standards: area benchmark

Therefore, the increase in materials used to achieve the Space Standards: Area benchmark of the 'urban house in paradise' will be:

$$= 2.55 \text{ m}^3$$

It has been assumed that none of these materials will be required to be replaced during the 120 year design life span of the dwelling. Analysis into the life expectancies of building components demonstrates that these materials will, through careful specification, be capable of lasting the full life span of the dwelling.[9] Therefore, spread across the design life span of the dwelling, this will equate to an equivalent annual resource use of:

2.55 / 120 $= -$ **0.021 m³.a⁻¹**

The area of land that is consumed in extracting these materials will be:

Mass of concrete:

0.60 x 1200 = 720 kg

area of land:

$0.72 \times 9.49049 \times 10^{-6}$ = 0.000007 ha

Mass of timber:

0.46 x 700 = 322.0 kg

area of land:

0.322 x 0.20205519 = 0.065 ha

The total area of land saved, spread across the life span of the dwelling:

(0.000007+ 0.065) / 120 $= -0.000544\ ha.a^{-1}$

$= -$ **5.461 $m^2.a^{-1}$**

5.3.30 Space Standards: Volume

The same methodology can also be used to determine the increase in resources that would be created by the benchmark of the Space Standards: Volume criterion. However, in the case of this criterion the ceiling heights will vary in order to achieve the new volume benchmarks; for the 'typical' dwelling the ceiling height will be taken as 2.3 m and for the 'urban house in paradise' it will be taken as 3.0 m. The values that are used will be the 'typical' values derived in the previous criterion, and the values of the 'urban house in paradise' will be those derived in the Deconstruction and Demolition: Recycling of Materials criterion, as these were based on the benchmark of this criterion. The one for the 'urban house in paradise' will have the volume increased to the benchmarked value. The algorithms used produce the following values:

[9] Research Steering Group of the Building Surveyor's Division and the Building Research Establishment. *Life Expectancies of Building Components*, London: Royal Institute of Chartered

Material	Volume of Material (m^3)		
	'Typical'	'u h in p'	Increase (inc recvc'd mats)
Insulation	16.21	22.39	0.0
Concrete block	6.81	11.39	1.15
Timber	3.96	4.74	0.59
Brick	3.18	4.46	0.32
Concrete	3.42	4.07	0.13
Plaster/board	3.11	4.01	0.9
Hardcore	1.52	1.87	0.0
Screed	0.30	0.38	0.08
Glass	0.67	0.71	0.04
Felt	0.23	0.30	0.07
Total	39.41	53.41	3.21

Increase in material use due to space standards: volume benchmark

Therefore, the increase in materials used to achieve the Space Standards: Volume benchmark of the 'urban house in paradise' will be:

$$= 3.21 \text{ m}^3$$

Spread across the design life span of the dwelling, this will equate to an equivalent annual resource use of:

$$3.21 / 120 \qquad = -\mathbf{0.027\ m^3.a^{-1}}$$

The area of land that is consumed in extracting these materials will be:

Mass of concrete:

$$1.15 \times 1200 \qquad = 1{,}380 \text{ kg}$$

area of land:

$$1.38 \times 9.49049 \times 10^{-6} \qquad = 0.000013 \text{ ha}$$

Mass of timber:

$$0.59 \times 700 \qquad = 413.0 \text{ kg}$$

area of land:

$$0.413 \times 0.20205519 \qquad = 0.084 \text{ ha}$$

Surveyors, August 1992.

The total area of land saved, spread across the life span of the dwelling:

(0.000013 + 0.084) / 120 = - 0.00070 ha.a^{-1}

= - 7.028 $m^2.a^{-1}$

5.3.31 Thermal Performance

The Energy Consumption: Inhabitation criterion will determine the contribution made to the reduction in natural resource consumption through improvements in the efficiency of a number of factors that contribute to the overall energy consumption of the dwelling. However, there will be a lesser benefit through solely increasing the thermal performance of the fabric of the dwelling; this value will also be affected by the increase in the embodied energy of the fabric.

In order to determine the magnitude of these effects, the model of the 'urban house in paradise' that was developed for the Deconstruction and Demolition: Recycling of Materials criterion, will be used also. This will assist in the purposes of relative comparability of data. Two scenarios were taken, firstly with the dwelling insulated to current Building Regulation standards, and secondly to the standards of the Thermal Performance benchmark of the 'urban house in paradise'. The annual energy consumption was determined using the SAP model for both scenarios, and the embodied energy of the additional insulation was also calculated.

The reduction in energy consumption for space heating was determined as 569 kWh.a^{-1}. The increase in the embodied energy was determined as 5,395 kWh; spread across the design life span of the dwelling, this would equate to an annual equivalent value of 45.0 kWh.a^{-1}. The natural resource depletion that will arise out of the consumption can be determined as:

Space heating (gas): 569 x 0.12 = 68.3 kg natural gas.a^{-1}

Using the densities of this fuel, this value can be converted into the volume of natural resources that will be saved:

68.3 / 0.67 = 101.9 m^3 natural gas.a^{-1}

For the additional insulation, there will potentially be two sources of natural resource consumption. The first will be from the embodied energy, and the second will be from the insulation itself, if it does not originate from a recycled source.

Embodied energy (1:1:1):

electricity:	15.0 x 0.14	= 2.10 kg coal.a^{-1}
	15.0 x 0.06	= 0.90 kg natural gas.a^{-1}
	15.0 x 0.01	= 0.15 kg petroleum.a^{-1}
gas:	15.0 x 0.12	= 1.80 kg natural gas.a^{-1}
petroleum	15.0 x 0.13	= 1.95 kg petroleum.a^{-1}

Therefore, the total reduction in natural resources from embodied energy consumption is:

= 2.10 kg coal.a^{-1}
= 2.70 kg natural gas.a^{-1}
= 2.10 kg petroleum.a^{-1}

Using the densities of these fuels, these values can be converted into the volume of natural resources that will be saved:

2.10 / 1500	= 0.0014 m^3 coal.a^{-1}
2.70 / 0.67	= 4.03 m^3 natural gas.a^{-1}
2.10 / 800	= 0.0026 m^3 petroleum.a^{-1}
	= 4.034 m^3 natural resources.a^{-1}

The additional volume of insulation that is required to achieve the thermal performance benchmarks for the model analysis is 23.5 m^3, however it is benchmarked that all insulation should be derived from recycled sources and will not therefore have an impact on natural resource consumption.

This would mean that the total reduction in the consumption of natural resources by the thermal performance benchmarks, would be:

Recycled insulant: 101.9 – 4.034 **= 97.9 m^3.a^{-1}**

This value should be treated with a degree of caution. As this criterion was concerned only with the direct effects of increasing the thermal performance, all other parameters were kept constant during the energy consumption modelling. Therefore no account is made of the consequent impacts of increasing the standard, such as affects on the type of heating system that would be specified. All of these will be accounted for by the Energy Consumption: Inhabitation criterion.

5.3.32 Use of Recycled Materials

In the recycling of deconstruction and demolition there may be a downgrading of the use of the material, for example concrete which is ground to make hardcore or aggregate, rather than being able to reuse that material for the same purpose, such a timber flooring. Therefore, the potential for using recycled materials within the 'urban house in paradise' will not, by default, be the same mass or volume as the quantity of materials that are recycled when a building is demolished.

The benchmark for the use of recycled materials is based on a percentage of the volume of material that should be derived from recycled sources for a variety of material types. These are:

Material	Proportion from recycled source (%)
Concrete	85
Hardcore	100
Insulation	100
Masonry	75
Timber	25

Proportion of materials from recycled source

Under the Deconstruction and Demolition: Recycling of Materials criterion an analysis was made of the level of materials that could be used to construct an 'urban house in paradise', conducted. This can also be used here to determine the volume of materials that will be derived from recycled sources, and thereby not from virgin natural sources, on the basis of the above benchmarks. The results of this analysis are summarised in the following table.

Material	Volume of materials in dwelling (m^3)
Insulation	22.39
Concrete block	11.39
Timber	4.46
Concrete	4.07
Plaster/board	4.01
Hardcore	1.87
Screed	0.38
Glass	0.071
Felt	0.03

Volume of materials used in the construction of the dwelling

The benchmarks can be used to translate these values into the volume of materials that will be from recycled sources:

Material	Volume of materials (m^3)
Insulation	22.39
Concrete block	8.54
Timber	1.12
Brick	3.35
Concrete	3.46
Plaster/board	0
Hardcore	1.87
Screed	0
Glass	0
Felt	0
Total	40.7

Volume of materials from recycled sources used in the construction of the dwelling

Divided across the design life span of the dwelling, this will equate to an annual reduction in the consumption of natural resources of:

40.7 / 120 = **0.34 m^3**

The area of land that would have been consumed in the extraction of these materials can be determined as follows:

Mass of concrete:

8.54 x 1200 = 10,248.0 kg

area of land:

$10.25 \times 9.49049 \times 10^{-6}$ = 0.000097 ha

Mass of timber:

1.12 x 700 = 784 kg

area of land:

0.784 x 0.20205519 = 0.159 ha

Mass of hardcore:

1.87 x 1500 = 2,805.0 kg

area of land:

$2.81 \times 9.49049 \times 10^{-6}$ = 0.000027 ha

The total area of land saved, spread across the design life span of the dwelling:

(0.000097 + 0.159 + 0.000027) / 120 = $0.00132\ ha.a^{-1}$

$=13.24\ m^2.a^{-1}$

5.3.33 Use of Renewable Raw Materials

The timber that comes from a managed source will still have a negative impact on natural resources through the consumption of land that is used to produce the timber. The volume of timber that will be derived from renewable resources to construct the model dwelling used in the Deconstruction and Demolition: Recycling of Materials criterion is 75 percent of 4.74 m^3, or 3.56 m^3. The land consumed in producing this timber can be determined as follows:

Mass of timber:

3.555 x 700 = 2,488.5 kg

area of land:

2.49 x 0.20205519 = 0.504 ha

The total area of land saved, spread across the design life span of the dwelling:

0.504 / 120 $= 0.0042\ ha.a^{-1}$

$= 42.0\ m^2.a^{-1}$

This means that the land is, under this benchmark, replaced through the renewing of the resource. Therefore, the contribution will be the land area minus the timber that is lost:

42.0 – 3.56 **$= 38.45\ m^2.a^{-1}$**

5.3.34 Utilisation of Local Resources

The only determinable effect that the utilisation of local resources may have on the reduction of pollution emissions will be through the reduction in transport. It has not been possible to determine the magnitude of total energy consumed through this criterion, and the mix of fuel types that would be used. Also, a benchmark for the typical dwelling could not be determined. Therefore it is not possible to establish the relative contribution of this criterion to the parameter of the reduction of natural resource consumption.

5.3.35 Water Consumption: Construction

From the benchmark analysis of this criterion, it was determined that the typical and 'urban house in paradise' benchmarks of water consumed during the construction of the dwelling are 34.1 and 8.5 litres per square metre. For the average occupancy of dwellings in the United Kingdom, of 2.4, the Space Standards analysis gives a typical dwelling area of 48.5 m^2; for the 'urban house in paradise' this rises to 59.8 m^2. Therefore, the quantity of water consumed in the construction of these two dwellings can be determined as,

48.5 x 34.1 = 1,653.8 litres

59.8 x 8.5 = 508.3 litres

∴ reduction = 1,144.7 litres

Accounting for the life span of the dwelling, the annual equivalent reduction will be:

1,144.7 / 120 $= 9.54\ litres.a^{-1}$

To convert this to a value in terms of volume, one litre of water has a mass of 1 kg; the density of water is 1000 $kg.m^{-3}$. Therefore, the reduction will equate to a volumetric saving of:

9.54 / 1000 $= 0.0095\ m^3.a^{-1}$

It was also determined that the reduction of 153.5 litres of potable water consumption per person per day will equate to an energy reduction of 0.08 kWh of energy per day. Therefore, the reduction of 9.54 litres per annum will equate to an energy reduction of 0.005 $kWh.a^{-1}$. The generation of that energy will create pollution. For the purposes of this calculation, it will be assumed that all of this energy will be electricity.

Data for the resources consumed in the consumption of this energy can be taken from the Energy Consumption: Inhabitation criterion:

0.005 x 0.14 = 0.0007 kg coal

0.005 x 0.06 = 0.0003 kg natural gas

0.005 x 0.01 = 0.00005 kg petroleum

For comparability with the other criteria within this parameter, these figures can be converted into volumetric values from the density of each fuel:

0.0007 / 1500 = 4.67×10^{-7} m^3 $coal.a^{-1}$

0.0003/ 0.67 = 0.00045 m^3 natural $gas.a^{-1}$

0.00005 / 800 = 6.25×10^{-8} m^3 $petroleum.a^{-1}$

In total, the reduction in natural resource consumption will be:

0.00045 + 0.0095 = **0.010 $m^3.a^{-1}$**

5.3.36 Water Consumption: Inhabitation

From the benchmark analysis, it has been determined that the water consumption during the period of in habitation of the 'urban house in paradise' will be 61.9 litres/person/day. Any grey water consumed would be from a recycled source, but both mains and rainwater can be counted as a resource. The typical domestic consumption was determined as 160 litres/person/day. Therefore, reduction will be:

160 – 61.9 = 98.1 litres per person per day

and 2.4 x 98.1 = 235 litres per household per day

and 235 x 365 = 85,936 litres per household per annum

To convert this to a value in terms of volume, one litre of water has a mass of 1 kg; the density of water is 1000 $kg.m^{-3}$. Therefore, the reduction will equate to a volumetric saving of:

85,936 / 1000 = 85.9 m^3

However, this calculation assumes that none of the water that has been saved through the reduction in the benchmark of consumption would have returned back to the hydrological cycle, and therefore would have in effect been recycled. As the wastewater from dwellings typically is returned to rivers and the sea, following degrees of processing, a proportion of the water that would have been consumed would be 'recycled'. Unless the level of water discharged can be related to the level of water that is returned to the hydrological cycle can be determined, and the true contribution to the reduction in consumption be determined, including the value of 85.9 m^3 will lead to a distortion of the weightings.

For the 'urban house in paradise' the level of mains consumption is benchmarked as 6.5 litres per person per day. During the analysis to determine the benchmark of Water Consumption: Inhabitation, it was determined that the reduction of 153.5 litres of potable water consumption per person per day will equate to an energy saving of 0.08 kWh of energy per day. Across the period of a year this will equate to an annual reduction of 29.2 kWh. Based on the mean occupancy figures for dwellings in the United Kingdom of 2.4 people per dwelling, this will equate to an annual household reduction of 70.1 kWh if the benchmark for the 'urban house in paradise' is achieved. Data for the resources consumed in the consumption of this energy can be taken from the Energy Consumption: Inhabitation criterion:

$$70.1 \times 0.14 = 9.81 \text{ kg coal}$$
$$70.1 \times 0.06 = 4.21 \text{ kg natural gas}$$
$$70.1 \times 0.01 = 0.701 \text{ kg petroleum}$$

For comparability with the other criteria within this parameter, these figures can be converted into volumetric values from the density of each fuel:

$$9.81 / 1500 = 0.007 \text{ m}^3 \text{ coal.a}^{-1}$$
$$4.21 / 0.67 = 6.28 \text{ m}^3 \text{ natural gas.a}^{-1}$$
$$0.701 / 800 = 0.0009 \text{ m}^3 \text{ petroleum.a}^{-1}$$

In total, the reduction in natural resource consumption will be:

$$0.007 + 6.28 + 0.0009 = \mathbf{6.29\ m^3.a^{-1}}$$

5.4 Prioritising – Contribution to the Reduction of Ozone Depleting Emissions

The following presents how the reduction in the emission per annum of ozone depleting gases achieved through adopting the benchmarks of the 'urban house in paradise' will be determined for each criterion, where applicable. The relative emissions are converted into the common unit of the equivalent emission of volatile organic compounds (VOCs), and the embodied impacts are divided by the design life span of the dwelling to establish an annual equivalent contribution to the reduction of emissions.

5.4.1 CO_2 Emissions: Construction and Deconstruction

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.2 CO_2 Emissions: Inhabitation

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.3 Carbon Intensity

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.4 Construction Period

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.5 Contextual Significance of the Site

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.6 Deconstruction and Demolition: Recycling of Materials

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.7 Design Life Span

The contribution of the Design life span benchmark to the reduction of greenhouse gases will be the cumulative effect of increasing the design life span of the dwelling by 60 years. To determine this, each criterion, where applicable, will be taken individually and then the contributions all summed to establish an overall contribution to the reduction of ozone depleting emissions.

Ecological Weight: Embodied Energy

On the basis of the average occupancy level and the Space Standards: Area benchmark, the embodied energy for the 'urban house in paradise' is 59.8 x 250 = 14,950 kWh. Therefore, the effect of the design life span benchmark will be:

$14{,}950 / 60 = 249.2 \text{ kWh.a}^{-1}$

$14{,}950 / 120 = 124.6 \text{ kWh.a}^{-1}$

$\therefore$ effect of life span $= 124.6 \text{ kWh.a}^{-1}$

The pollution emissions associated with this reduction are:

Electricity:	41.5 x 0.110	= 4.57 gVOC.a^{-1}
Gas:	41.5 x 0.036	= 1.49 gVOC.a^{-1}
Petroleum	41.5 x 1.681	= 69.8 gVOC.a^{-1}
		= 75.9 gVOC.a^{-1}

Energy Consumption: Construction Processes

The emission of greenhouse gases created by these processes will be included within the overall calculation of the Ecological Weight: Embodied Energy criterion, and therefore should not be included here so that its effect is not double counted when the cumulative total is determined.

Standards: Area and Volume

Although during the calculation of the effect of the Space Standards: Area and Volume benchmarks on pollutant emission the life span of the dwelling was used, it will not be a part of the cumulative effect of the design life span benchmark. The Ecological Weight: Embodied Energy criterion has already taken account of the increase in area created by the Space Standards benchmark.

Thermal Performance

The impact of increasing the level of thermal performance of the dwelling's fabric will be accounted for within the Ecological Weight: Embodied Energy criterion, and will not be assessed here so as no to double count when calculating the cumulative effect.

Therefore, in total the reduction of ozone depleting emissions achieved through increasing the design life span of the dwelling to the benchmark of the 'urban house in paradise' will be:

75.9 **= 75.9 gVOC.a^{-1}**

5.4.8 Density: Quantitative

As for the diversity criterion below, benchmarking the density to the level proposed by Friends of the Earth, which is based on thresholds at which public transport and walking become more chosen options, will have a reduction in private transport use, and therefore a reduction in the emission of VOCs. However, due to the complexities involved in determining a quantitative reduction, it is beyond the scope of this study to undertake an analysis of the magnitude of such reduction in terms of the benchmark proposed.

5.4.9 Density: Qualitative

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.10 Diversity: Programme

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases. An indirect effect that creating a mixed-use project would be through the reduction in emissions arising from transport through providing facilities within walking distance. However, it is considered to be beyond the scope of this study to undertake an analysis of the magnitude of such reduction in terms of the programmatic diversity benchmark proposed, due to the complexity of such a calculation.

5.4.11 Domestic Waste

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.12 Ecological Significance of the Site

As determined under the parameter of Contribution to the Reduction of Pollution, plants are capable of absorbing forms of pollution; different species have varying capabilities in the rate of absorption, and different rates of absorption for different pollutants for a given species. However, it has not been possible to determine what species are assimilators of VOCs, and therefore to determine a quantitative value of absorption. Because this benchmark is based on diversity of species, even if this had been possible, it would have proved difficult to justify this value on the basis that different species absorb pollutants at different rates. Therefore sites with varying species diversity would be likely to absorb varying levels of VOCs.

5.4.13 Ecological Weight: Embodied Energy

The combustion of fossil fuels to fulfil the embodied energy demands of the dwelling will give rise to the emissions of volatile organic compounds (VOCs), which have been identified as contributing to ozone layer depletion.[1]

The benchmark analysis can be used to determine comparable embodied energy values for a 'typical' dwelling and an 'urban house in paradise' based on the Space Standards: Area benchmark, using the average occupancy level from census data, and the Ecological Weight: Embodied Energy benchmark:

'typical' =	1,000 x 48.5	= 48,500 kWh
'urban house in paradise' =	250 x 59.8	= 14,950 kWh

Therefore, the reduction in embodied energy that will be achieved through the benchmark reduction is:

48,500 – 14,950 = 33,550 kWh

Across the design life span of the dwelling, this is the equivalent annual reduction of:

33,500 / 120 = 279.2 $kWh.a^{-1}$

The Building Research Establishment's *Methodology for Environmental Profiles* determines the emissions associated with fuel consumption from the NETCEN National Atmospheric

[1] National Society for Clean Air and Environmental Protection. *Pollution Handbook*, London: NSCA, 1997.

Emissions Inventory, based on 1996 figures which are the most recent available.[2] These figures also take into account the upstream emissions arising from the extraction, refining, and supply, as well as the energy consumed in extraction, refining and supply of the energy to conduct to processes:

Emissions	Emission factors of fossil fuels (g.kWh^{-1})		
	Gas	Oil	Coal
VOCs	0.032	0.255	0.065

Emission factors of fossil fuels

In terms of generating electricity, accounting for the inefficiencies of power stations and transmission after generation means that per kWh of delivered energy the emissions be:

Emissions	Emission factors of fossil fuels (g.kWh^{-1} delivered electricity)		
	Gas	Oil	Coal
VOCs	0.080	0.638	0.217

Emission factors of fossil fuels, in terms of delivered electricity

On the basis of the fossil fuel mix used to generate electricity, derived from the Digest of United Kingdom Energy Statistics 1998[3] (33 percent coal, 31 percent gas, 26 percent nuclear and 2 percent oil), it can be determined that to generate one kWh of electricity will create the following emissions form each fuel type:

Emissions	Emission factors on the basis of generation mix (g.kWh^{-1})			
	Gas	Oil	Coal	TOTAL
VOCs	0.025	0.013	0.072	0.110

Emission factors of fossil fuels on the basis of generation mix

[2] Howard, Nigel, Suzy Edwards and Jane Anderson. *BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings*. London: Construction Research Communications Limited, 1999.
[3] Department of Trade and Industry. *Digest of United Kingdom Energy Statistics 1998*, London: HMSO, 1998.

The values for natural gas and petroleum consumption will account for the typical relative efficiency of appliances consuming those sources.[4]

Assuming a 1:1:1 ratio for the mixture of electricity : gas : petroleum for fuel types used during the period of embodied energy consumption gives a value per fuel type of 93.1 kWh/a. Therefore, the emissions associated with each fuel are:[5]

Electricity:	93.1 x 0.110	= 10.2 gVOC.a^{-1}
Gas:	93.1 x 0.036	= 3.35 gVOC.a^{-1}
Petroleum	93.1 x 1.681	= 156.4 gVOC.a^{-1}

Therefore, in total the reduction in emissions is:

= 170.0 gVOC.a^{-1}

5.4.14 Ecological Weight: Embodied CO_2 Emission

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.15 Energy Consumption: Construction Processes

As for the other criteria that benchmark a reduction in the consumption of fossil fuel, there will also be a reduction in emissions of VOCs. The reduction in energy consumption during on site construction can be determined from the benchmark analysis. From the mean occupancy value, Space Standards: Area and Energy Consumption: Construction Processes benchmarks, the reduction in energy consumption can be determined as:

'typical':	150 x 48.5	= 7,275 kWh
'urban house in paradise'	75 x 59.8	= 4,485 kWh
∴ reduction =	7,275 – 4,485	= 2,790 kWh

Across the design life span of the dwelling, this will equate to an annual equivalent reduction of:

2,790 / 120 = 23.3 kWh.a^{-1}

[4] Thomas, Randall (ed). *Environmental Design*, London: E & F N Spon, 1996.

[5] The values determined for NOx emissions have had the N_2O component deducted from the NOx total, as N_2O emissions are counted under the parameter of Contribution to the Reduction of the Greenhouse Effect; not removing them for the Contribution to the Reduction of Pollution parameter would double count them.

In terms of fuel mix, gas will not be used as much for a fuel source during on site construction, and therefore the ratio has been proposed as 4.5:4.5:1 for electricity : petroleum : gas.

Therefore, the reduction in the emissions of ozone depleting emissions by fuel type will be:

Electricity:	10.5 x 0.110	= 1.15 gVOC.a^{-1}
Gas:	2.33 x 0.036	= 0.084 gVOC.a^{-1}
Petroleum:	10.5 x 1.681	= 17.6 gVOC.a^{-1}

Therefore, in total the reduction in ozone depleting emissions is:

= 18.8 gVOC.a^{-1}

5.4.16 Energy Consumption: Inhabitation

The values for the emissions per kWh for each fossil fuel type, derived under the Ecological Weight: Embodied Energy in Materials, can be used here to determine the ozone depleting emissions from the energy consumed during the period of inhabitation. The electricity saving by moving from the energy consumption of the 'typical' dwelling to that of the 'urban house in paradise' would be:

Typical spec built dwelling	= 48.5 x 38	= 1,843
'urban house in paradise'	= 59.8 x 10	= 598
∴ reduction	= 1,843 - 598	= 1,245 kWh.a^{-1} electricity

Therefore, the reduction in ozone depleting emissions as a result of the reduction in electricity consumption is:

1,245 x 0.110 = 137.0 gVOC.a^{-1}

In terms of gas consumption, there will also be a consequential VOC emission, which will also be affected by the efficiency of the appliance converting the energy. From the Energy Consumption: Inhabitation benchmark, the saving in energy typically provided by gas can be derived as 6,669.0 kWh.a^{-1}. This value includes the inefficiency of the individual appliance. Therefore the emissions is:

6,669.0 x 0.036 = 240.1 gVOC.a^{-1}

Therefore, in total the reduction in ozone depleting emissions is:

= 377.1 gVOC.a^{-1}

5.4.17 Energy Generation: Inhabitation

This criterion will consider the contribution that will be made to the reduction of ozone depleting emissions if the energy demand of the dwelling were created from renewable sources as opposed to fossil fuels. If the area of the dwelling, based on typical occupancy figures is 59.8 m^2, then the overall reduction in fossil fuel consumption will be:

12 x 59.8	= 717.6 kWh.a^{-1} gas
13 x 59.8	= 777.4 kWh.a^{-1} electricity

The emissions that are associated with the burning of these fuel types have been determined under the Energy Consumption: Inhabitation benchmark. Therefore, the ozone depleting emissions that would be created by these energy consumption values can be determined as:

Gas:	717.6 x 0.036	= 25.8 gVOC.a^{-1}
Electricity:	777.4 x 0.110	= 85.5 gVOC.a^{-1}

Therefore, in total the reduction in ozone depleting emissions that would be achieved by adopting the benchmark of Energy Consumption: Inhabitation is:

= 111.3 gVOC.a^{-1}

5.4.18 Green Space

As was discussed under the Ecological Significance of the Site criterion, plants can also absorb forms of pollution; different species have varying capabilities in the rate of absorption, and different rates of absorption for different pollutants for a given species. However, it has not been possible to determine what species are assimilators of VOCs, and therefore to determine a quantitative value of absorption. Even if this had been possible, it would have proved difficult to justify this value on the basis that different species absorb pollutants at different rates, and therefore different green spaces, with different species diversity, would be likely to absorb varying levels of VOCs.

5.4.19 Lifecycle Cost

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.20 Nitrogen Oxide Emissions

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.21 Other Ecological Impacts of Materials

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.22 Other Greenhouse Gas Emissions

Methane

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

CFCs

The Montreal Protocol of 1989, on substances that deplete the ozone layer, sought to commit industrialised nations to cut CFC consumption by half by the year 2000. Its subsequent revision in London in 1990 led to the amendment of a complete phase out of CFCs by January 2000. This was followed in 1992 by a revision in Copenhagen to cease the production of CFCs from 1 January 1996.[6] Therefore the emission of CFCs will not be a relevant to the thesis.

HCFCs

The reduction of HCFCs will be achieved through the specification of insulation materials that have been produced without using any of the variants of the gas as blowing agents. It has been possible to determine that the manufacturer Cellotex uses the HCFC 141B as a blowing agent in the production of some insulation materials.[7] The ozone depleting potential of this gas is 0.08, where the benchmark gas CFC R11 = 1.[8]

---

[6] Ibid., Addenda February 1993.
[7] Personal communication with Cellotex and Ecotherm Limited.
[8] Thomas, Randall (ed). Op. Cit.

As noted under the Contribution to Reduction of the Greenhouse Effect, only one manufacturer would supply details of the quantity of HCFC used in the production of insulation foams. In every case where a reason was given for not supplying values, this was due to the confidentiality of such data. Therefore, the calculation of the effect of this benchmark will be based on this value of 140 kgHCFC per tonne of insulation.[9]

The volume of insulation used to construct the analysis model of the 'urban house in paradise', in the Deconstruction and Demolition: Recycling of Materials criterion in the Contribution to Reduction of Natural Resource Consumption parameter, is 22.39 m^3. The volume of one tonne of insulation with a density of 24 $kg.m^{-3}$ is 41.67m^3, which will have an HCFC content of 140 kg. Therefore, the insulation within the dwelling would have an HCFC content of:

$$(22.39 / 41.67) \times 140 \qquad = 75 \text{ kgHCFC}$$

As the relative depletion potential between the HCFC and VOCs has been unable to be determined, they will assume to be equal. Should this information be derived at a future date, it will be a relatively straightforward process to update the value, using an identical process used to convert each of the greenhouse gases into values of equivalent CO_2 emissions, in the parameter of Contribution to the reduction of Greenhouse Gas Emissions.

Spread across the design life span of the dwelling, this is an annual equivalent of,

$$75 / 120 \qquad = 625 \text{ g141B.a}^{-1}$$

However, this value is based on the assumption that all of the gas encapsulated within the insulation will be released. The value of the proportion of gas released during the manufacture of HCFC insulation is 5 percent.[10] Adopting this proportion gives a value for the reduction in emissions of,

$$625 \times 0.05 \qquad = \mathbf{21.88 \text{ g141B.a}^{-1}}$$

---

[9] Two values were given by the manufacturer, one of 140 kgHCFC per tonne for foam with a density of 24 $kg.m^{-3}$ and 95 kgHCFC per tonne for foam with a density of 55 $kg.m^{-3}$. The former value is used because the manufacturer states that this is the one most frequently supplied, as it both reduces material costs and has a better value of thermal conductivity.

[10] Personal communication with Mr G. W. Ball, President of the British Rigid Urethane Foam Manufacturer's Association, 25 April 2000. The communication stated that 5 percent of the added blowing agent is lost during manufacture. None is lost during use, and upon demolition the insulation is collected and combusted to destroy the blowing agent without emission to the air, in accordance with a draft EU Directive on demolition waste.

However, this value assumes that the insulation that would be specified in the 'typical' dwelling would always one that used an HCFC blowing agent. Due to the quantity of other materials that do not, this is unlikely.

Tropospheric Ozone

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

Nitrous Oxide

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.23 Pollution: Energy Consumption Inhabitation

This benchmark is a measure of the level of pollution that is caused by the energy consumed during the period of inhabitation, measured on a relative scale, per kilowatt-hour. It is related to, but assessed independently, of the Energy Consumption: Inhabitation benchmark, and is intended to ensure that fuels are not used that cause higher levels of pollution emissions when alternatives are available. As the benchmark is assessed independently of the level of energy consumption, the impact in terms of this parameter need not be considered in terms of both the level of energy consumption in the 'typical' dwelling and the 'urban house in paradise', but rather should be determined on the basis of only the latter.

Therefore, the energy consumption of the 'urban house in paradise', from the Energy Consumption: Inhabitation benchmark is:

$$25 \times 59.8 \qquad = 1495\ kWh.a^{-1}$$

As the impact of some of the pollution emissions under this benchmark will be considered under other parameters, namely those that contribute to pollution not considered by the this parameter, the following table shows which are being considered here:

Dwelling	VOC Emission (g.kWh^{-1} delivered)
'Typical'	0.051
'Urban house in paradise'	0.036

VOC emission of the typical dwelling and 'urban house in paradise'

The level of emissions arising from each benchmark can be determined as,

Typical = 0.051 x 1495 = 76.2 gVOC.a^{-1}

'u h in p' = 0.026 x 1495 = 38.9 gVOC.a^{-1}

Therefore, the reduction in ozone depleting emissions which would be achieved by moving from the standard of the 'typical' dwelling to that of the 'urban house in paradise' is,

76.2 – 38.9 = **37.3 gVOC.a^{-1}**

5.4.24 Procurement Strategy

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.25 Quality of Internal Environment: Indoor Pollution

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.26 Quality of Internal Environment: Daylight

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.27 Quality of Internal Environment: Ventilation and Air Tightness

The Energy Consumption: Inhabitation criterion will determine the contribution made to the reduction in emissions through improvements in the efficiency of a number of factors that contribute to the overall energy consumption of the dwelling. However, reducing the heat loss that occurs through the ventilation rate and the air tightness of the dwelling's structure and fabric, as a contributor to this saving, will have a lesser impact upon reducing the energy consumption.

In order to determine the magnitude of these effects, the model of the 'urban house in paradise' that was developed for the Contribution to the Reduction of Natural Resources parameter, defined by a number of the benchmarks, will be used also. This will assist in the purposes of relative comparability of data. Two scenarios were taken, firstly of a dwelling with natural ventilation and an air tightness value both representative of a 'typical' dwelling, and secondly to the standards of the Quality of the Internal Environment: Ventilation and Air Tightness benchmark of the 'urban house in paradise'. The annual energy consumption, determined using the SAP model, was then established for both scenarios.

The reduction in energy consumption for space heating was determined as 1,966.7 $kWh.a^{-1}$. The increase in energy consumption as a result of the additional fans was determined as 59.8 $kWh.a^{-1}$. The emissions of ozone depleting material that will arise out of the reduction and consumption can be determined as:

Space heating (gas):	1,966.7 x0.036	= 70.8 $gVOC.a^{-1}$

The additional energy consumption, that powers the fans, will be electrical:

Electricity:	59.8 x 0.110	= 6.58 $gVOC.a^{-1}$

Therefore, the effect on ozone depleting emissions created by achieving the Ventilation and Air Tightness benchmark of the 'urban house in paradise' is:

70.8 – 6.58	**= 64.2 $gVOC.a^{-1}$**

5.4.28 Recycling of Construction Waste

Whilst there will be an embodied energy content of recycled materials, these will be accounted for within the Ecological Weight: Embodied Energy criterion. Therefore, in terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.29 Recyclability of Building: Adaptability

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.30 Space Standards: Area

Increasing the space standards of the dwelling will have an impact on the overall emissions of that dwelling, due to the increased energy consumption, which is benchmarked per unit area.

For the average occupancy of dwellings in the United Kingdom, of 2.4, the Space Standards analysis gives a dwelling area of 48.5 m^2; for the 'urban house in paradise' this rises to 59.8 m^2, an increase of 11.3 m^2.

Therefore, the increase in ozone depleting emissions that will occur as a result of the average increase in Space standards will be:

Embodied energy:		(11.3 x 250) / 120	= 23.5 $kWh.a^{-1}$
	Electricity:	7.85 x 0.110	= 0.86 $gVOC.a^{-1}$
	Gas:	7.85 x 0.036	= 0.28 $gVOC.a^{-1}$
	Petroleum	7.85 x 1.681	= 13.2 $gVOC.a^{-1}$

Therefore, in total the additional embodied energy ozone depleting emissions will be:

= 14.3 $gVOC.a^{-1}$

During inhabitation:	11.3 x 15	= 169.5 kWh gas
	11.3 x 10	=113.0 kWh electricity

Gas:	169.5 x 0.036	= 6.10 $gVOC.a^{-1}$
Electricity:	113.0 x 0.110	= 12.4 $gVOC.a^{-1}$

Therefore, in total the additional emissions during inhabitation will be:

= 18.5 $gVOC.a^{-1}$

Therefore, in effect the contribution to the reduction of ozone depleting emissions is:

= - 32.8 $gVOC.a^{-1}$

5.4.31 Space Standards: Volume

Because the energy consumption both for both embodied energy and during the period of inhabitation is quantified by the benchmarks per unit area, the Space Standards: Volume criterion will have no additional effect. Therefore, in effect the contribution to the reduction of ozone depleting emissions is:

= - 32.8 gVOC.a^{-1}

5.4.32 Thermal Performance

The Energy Consumption: Inhabitation criterion determined the contribution made to the reduction in ozone depleting emissions through improvements in the efficiency of a number of factors that contribute to the overall energy consumption of the dwelling. However, there will be a lesser benefit through solely increasing the thermal performance of the fabric of the dwelling; this value will also be affected by the increase in the embodied energy of the fabric.

In order to determine the magnitude of these effects, the model of the 'urban house in paradise' that was developed for the Contribution to the Reduction of Natural Resources parameter, defined by a number of the benchmarks, was used also. This assisted in the purposes of relative comparability of data. Two scenarios were taken, firstly with the dwelling insulated to current Building Regulation standards, and secondly to the standards of the Thermal Performance benchmark of the 'urban house in paradise'. The annual energy consumption, determined using the SAP model, was established for both scenarios, and the embodied energy of the additional insulation was calculated.

The reduction in energy consumption for space heating was determined as 569 kWh.a^{-1}. The increase in the embodied energy was determined as 5,395 kWh; spread across the design life span of the dwelling this would equate to an annual equivalent value of 45.0 kWh.a^{-1}. The ozone depleting emissions that would arise out of the consumption can be determined as:

Space heating (gas): 569 x 0.036 = 20.5 gVOC.a^{-1}

Embodied (1:1:1):

electricity:	15.0 x 0.110	= 1.65 gVOC.a^{-1}
gas:	15.0 x 0.036	= 0.65 gVOC.a^{-1}
petroleum	15.0 x 1.681	= 25.2 gVOC.a^{-1}
		= 29.7 gVOC.a^{-1}

Therefore, the reduction in ozone depleting emissions is:

$$20.5 - 29.7 \quad = \mathbf{-9.2\ gVOC.a^{-1}}$$

Thus whist there is an reduction in the energy consumption, because the space heating is gas fuelled, which has a relatively low VOC emission level, whereas the embodied energy has a mixture of fuel sources, the actual annual emission level is increased.

The additional volume of insulation that is required to achieve the thermal performance benchmarks for the model analysis is 24.2 m^3. However, as the benchmark for Other Greenhouse Gases: HCFC requires that insulation materials should have an ozone depleting potential of zero, there will be no additional ozone depleting emission associated with this increase in mass.

This value must be treated with a degree of caution. As this criterion was concerned only with the direct effects of increasing the thermal performance, all other parameters were kept constant during the energy consumption modelling. Therefore no account is made of the consequent impacts of increasing the standard, such as affects on the type of heating system that would be specified. These are accounted for collectively by the Energy Consumption: Inhabitation criterion.

5.4.33 Use of Recycled Materials

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.34 Use of Renewable Raw Materials

In terms of its benchmark value, this criterion is considered to have no direct consequential reduction upon the emission of ozone depleting gases.

5.4.35 Utilisation of Local Resources

The only determinable effect that the utilisation of local resources may have on the reduction of pollution emissions will be through the reduction in transport. It has not been possible to determine the magnitude of total energy consumed through this criterion, and the mix of fuel types that would be used. Also, a benchmark for the typical dwelling could not be determined. Therefore it is not possible to establish the relative contribution of this criterion to the parameter of the reduction of ozone depleting emissions.

5.4.36 Water Consumption: Construction

From the benchmark analysis of this criterion, it was determined that the typical and 'urban house in paradise' benchmarks of water consumed during the construction of the dwelling are 34.1 and 8.5 litres per square metre. For the average occupancy of dwellings in the United Kingdom, of 2.4, the Space Standards analysis gives a typical dwelling area of 48.5 m^2; for the 'urban house in paradise' this rises to 59.8 m^2. Therefore, the quantity of water consumed in the construction of these two dwellings can be determined as,

48.5 x 34.1	= 1,653.8 litres
59.8 x 8.5	= 508.3 litres
∴ reduction	= 1,144.7 litres

Accounting for the life span of the dwelling, the annual equivalent reduction will be:

1,144.7 / 120	= 9.54 $litres.a^{-1}$

It was also determined that the reduction of 153.5 litres of potable water consumption per person per day will equate to an energy reduction of 0.08 kWh of energy per day. Therefore, the reduction of 9.54 litres per annum will equate to an energy reduction of 0.005 $kWh.a^{-1}$. The generation of that energy will create pollution. For the purposes of this calculation, it will be assumed that all of this energy will be electricity. The ozone depleting emissions that are associated with the generation of this energy can be determined using the data in the criterion of Energy Consumption: Inhabitation:

0.005 x 0.110	**= 0.0006 $gVOC.a^{-1}$**

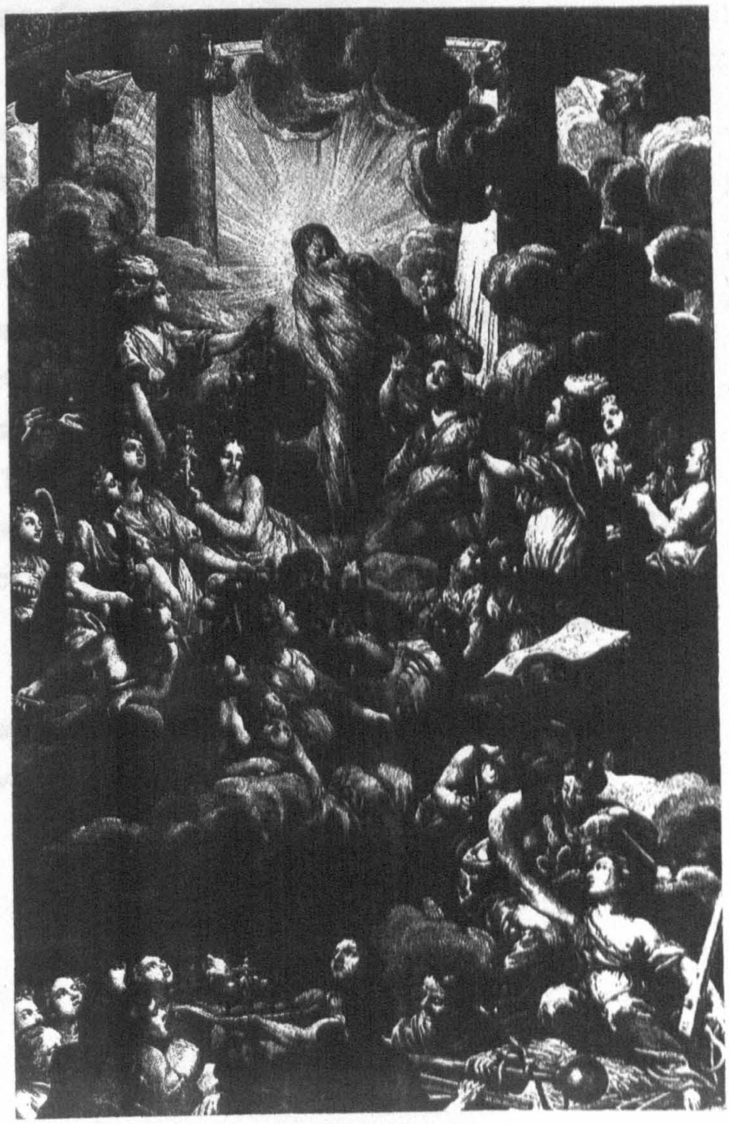
5.4.37 Water Consumption: Inhabitation

For the 'urban house in paradise' the level of mains consumption is benchmarked as 8 litres per person per day. During the analysis to determine the benchmark of Water Consumption: Inhabitation, it was determined that the reduction of 153.5 litres of potable water consumption per person per day will equate to an energy saving of 0.08 kWh of energy per day. Across the period of a year this will equate to an annual reduction of 29.2 kWh. Based on the mean occupancy figures for dwellings in the United Kingdom of 2.4 people per dwelling, this will equate to an annual household reduction of 70.1 kWh if the benchmark for the 'urban house in paradise' is achieved.

As for the other parameters, this energy is presumed to be all electricity. The ozone depleting emissions that are associated with the generation of this energy can be determined using the data in the criterion of Energy Consumption: Inhabitation:

$$70.1 \times 0.110 \qquad = \mathbf{7.71\ gVOC.a^{-1}}$$

Annexe 6



Validation Questionnaires

Annexe 6.0 Validation Questionnaires

This annexe contains the questionnaires completed by the specialists asked to participate in the validation the 'urban house in paradise' assessment tool, refer to chapter 11.0 in volume 1.

The first was completed by Geoffrey Brundrett, who is president of the Royal Society for Health, past president of the Chartered Institute of Building Services Engineers, and an authority on air tightness and ventilation in buildings. He was a member of the CIBSE Task Group involved in the production of TM23 on testing buildings for air leakage; The Chartered Institution of Building Services Engineers. *Technical Memorandum 23 – Testing Buildings for Air leakage*, London: CIBSE, October 2000. He reviewed the assessment tool from the perspective of a services engineer. The second questionnaire was completed by Ian Wroot, who is a practicing architect and senior lecturer at Liverpool John Moores University's Centre for Architecture, specialising in technology in architecture; he reviewed the assessment tool from the perspective of a project architect.

Urban Housing Performance Benchmark Assessment Tool

Validation Questionnaire

The aim of this questionnaire is to provide a framework for an assessment of the urban housing performance benchmark tool by a specialist after it has been used. Briefing on how to utilise the performance benchmark tool will be given to each validating assessor before its use. The tool is to be evaluated against the following questions, either by rating between 1 and 5, circling the appropriate value, or by indicating 'Yes' or 'No', as appropriate. Space is provided below each question for additional comments, such as details as to why the response has been given. In the case of 'Yes' or 'No' responses, elaboration is requested.

1 How do you rate the ease with which the performance benchmark tool is used to conduct an assessment of a dwelling?

Poor				Excellent
1	2	3	(4)	5

LOOKS FEARSOME BUT MUCH OF THE DATA IS NEEDED FOR THE DESIGN

2 How do consider the time taken to conduct an assessment of a dwelling using the tool, in the context of the detail of the outcomes?

Excessive		Acceptable		Short
1	2	(3)	4	5

TIME CONSUMING (2 HOURS) BUT MUCH OF IT IS NEEDED FOR THE STATUTORY S.A.P. RATING ANYWAY

3 How do you rate the probable accuracy of the predicted benchmarks?

Inaccurate		Acceptable		Very accurate
1	2	(3)	4	5

If there are specific areas that have influenced your response, please give details.

~~TWO~~ THREE POTENTIAL PROBLEM AREAS

(1) TOTAL ENERGY IS INCLUDED AS AN INDEPENDANT FACTOR — BETTER AS DEPENDANT

(2) VENTILATION SYTEMS NOT INCLUDED

(3) BUILDING MASS BECOMING AN IMPORTANT DESIGN FACTOR IN LOW ENERGY DESIGNS

4 Did a repeat assessment using the tool give the same results?

Yes / No If "No" please give details.

DID NOT DO A REPEAT

5 Do you feel that there are any areas of ambiguity within the assessment methodology of the performance benchmark tool?

Yes / No If "Yes" please give details.

YES - SEE 3 (1)

6 Are there any areas of the performance benchmark tool's assessment that you consider to be of particular significance?

Yes / No If "Yes" please give details.

YES — IT SHOWED EMBODIED ENERGY TO BE A SIGNIFICANT FACTOR

7 Are there any areas of the tool's assessment that you consider to be redundant?

Yes / No If "Yes" please give details.

NO

8 Are there any elements of a dwelling's performance that you consider the tool should assess but does not?

Yes / No If "Yes" please give details.

YES – VENTILATION

– HEALTH IMPLICATIONS

9 Are there any improvements that could be made to the tool?

Yes / No If "Yes" please give details.

— EXTEND TO INCLUDE SYSTEMS SUCH AS VENTILATION HEAT RECOVERY

— EXTEND TO GIVE BENEFIT FOR THERMAL MASS FOR HEAVY CONSTRUCTIONS

10 How relevant to you feel the performance benchmark tool to be, given the current drives for innovation that are being promoted in the house building industry?

Irrelevant				Very relevant
1	2	3	4	5

AS A STARTING POINT

11 Overall, how do you rate the success of the tool as a way in which to assess the performance of a dwelling? Please give details of your opinion.

Poor				Excellent
1	2	3	4	5

FOR THE BUILDING FABRIC PART OF THE DESIGN

12 Finally, do you have any further comments to offer?

— An interesting way of assessing + ranking the fabric part of a building design

— Links between insulation + energy use may need refinement when extended to low energy buildings

— Very appropriate to highlight infiltration importance now, because building regulations are reviewing changes to incorporate performance standards pressure testing

— Hope infiltration can be separated from ventilation in final version

Urban Housing Performance Benchmark Assessment Tool

Validation Questionnaire

The aim of this questionnaire is to provide a framework for an assessment of the urban housing performance benchmark tool by a specialist after it has been used. Briefing on how to utilise the performance benchmark tool will be given to each validating assessor before its use. The tool is to be evaluated against the following questions, either by rating between 1 and 5, circling the appropriate value, or by indicating 'Yes' or 'No', as appropriate. Space is provided below each question for additional comments, such as details as to why the response has been given. In the case of 'Yes' or 'No' responses, elaboration is requested.

1 How do you rate the ease with which the performance benchmark tool is used to conduct an assessment of a dwelling?

Poor				Excellent
1	2	(3)	4	5

A more elaborate hierarchical system could be incorporated for information input, so that more detailed information is only required if the user chooses advanced options at different stages.

2 How do consider the time taken to conduct an assessment of a dwelling using the tool, in the context of the detail of the outcomes?

Excessive		Acceptable		Short
1	(2)	3	4	5

Difficult to answer without knowing who the tool is intended for. It seems very advanced and time consuming for general use be architects and developers.

3 How do you rate the probable accuracy of the predicted benchmarks?

Inaccurate		Acceptable		Very accurate
1	2	3	(4)	5

If there are specific areas that have influenced your response, please give details.

I have not had the time to really test the tools accuracy, it would have to be pitted against traditional long hand calculations or similar software available in the market place.

4 Did a repeat assessment using the tool give the same results?

Yes / No If "No" please give details.

Yes

5 Do you feel that there are any areas of ambiguity within the assessment methodology of the performance benchmark tool?

Yes / No If "Yes" please give details.

No

6 Are there any areas of the performance benchmark tool's assessment that you consider to be of particular significance?

Yes / No If "Yes" please give details.

Yes

The embodied energy and energy use of appliance aspects of the tool is particularly interesting because I have never seen a software package that tackles these issues before. The raw data provided in the tables relating to these are useful in themselves although verification of the sources and probable accuracy of the statistics should be provided.

7 Are there any areas of the tool's assessment that you consider to be redundant?

Yes / No If "Yes" please give details.

No

But it could be overly detailed and onerous in places for realistic use.

8 Are there any elements of a dwelling's performance that you consider the tool should assess but does not?

Yes / No If "Yes" please give details.

No

There are a range of subjective values of course but these are in the realms of creativity not statistical assessment.

9 Are there any improvements that could be made to the tool?

Yes / No If "Yes" please give details.

Yes

Refer to answer 1

10 How relevant to you feel the performance benchmark tool to be, given the current drives for innovation that are being promoted in the house building industry?

Irrelevant				Very relevant
1	2	3	4	(5)

11 Overall, how do you rate the success of the tool as a way in which to assess the performance of a dwelling? Please give details of your opinion.

Poor				Excellent
1	2	3	(4)	5

Again flexibility of use would be a great benefit so that quick assessment can be made early on in the design process with a minimum of data input and more detailed performance model produced at various stages as more design data become available.

12 Finally, do you have any further comments to offer?

Very impressive so far.

Ian Wroot

Senior Lecturer
Centre for Architecture
Liverpool School of Art & Design

Annexe 7

Research Papers

Annexe 7.0 Research Papers

This annexe contains research papers that have been written and disseminated during the research period.

These papers were prepared for and delivered at the Housing Policy and Procurement colloquium, at Liverpool John Moores University on 29th June 2000. The subject matter is based on concepts being developed within the thesis.

7.1 Construction Task Force, Movement for Innovation and Construction Best Practice Programme: Relevance and Appropriateness to Innovation in a Wider Context

Abstract

There currently exists a significant drive toward improving the performance of the construction industry. In the Construction Task Force's report *Rethinking Construction* a chapter was dedicated to the issue of housing, following the publication of which, the Movement for Innovation (m4i) was established to oversee the implementation of the Task Force's objectives into the industry, and the Housing Forum to oversee innovation in house building. The two Government backed Millennium Community Competitions have specifically addressed the issue of housing performance in design, construction and inhabitation.

This paper will conduct a critique of the criteria and benchmark targets proposed by the Construction Task Force, and to be implemented through m4i and the Construction Best Practice Programme, in terms of the improvement of the performance of housing during design, construction and inhabitation. Attention will be paid to their relevance in the context of the increasingly significant determinants of ecological, economic and social sustainability. The paper will conclude in a proactive manner by making proposals for an alternative/complimentary agenda of performance criteria to those currently being considered by the industry.

Key Words

Benchmarks, Construction Best Practice Programme, Construction Task Force, Movement for Innovation, performance criteria, sustainability.

1.0 Introduction

Housing policy and procurement methods require to comprehensively change. There is no discernible improvement in what is being offered consumers:

* because of demonstrable excessive wastage and inefficiencies from land use to construction methods,
* because of energy profligacy especially during the period of inhabitation,
* because of the absence of community life within housing areas,
* because of a lack of adaptability of houses to meet material change,
* and because of an overarching lack of value for money.

These five areas of concern suggest an absence of short and mid-term ecological, economic and social sustainability.

In order to address this need for change, accent on costs being the sole arbiter of decision making needs to give way to value being placed on a wider agenda of items, land needs to be more efficiently used, and behaviour of policy makers and housing providers needs to radically adapt. Such changes will be achieved through community-led housing practices, a massive increase in practical research and development, acknowledgement that improvements will only emerge through design time, a methodological setting and monitoring of benchmarks, and the creation of new types of policy organisms and provider companies.

This paper addresses one aspect of this need for change, namely a critical appraisal of the current drive toward benchmarking improvements to the performance of the construction, and explicitly within that, house building industry, in terms of the increasingly significant determinants of ecological, economic and social sustainability.

2.0 The Global Context

The rapid advances in technology that occurred during the last century were followed by a realisation that our increasingly 'development orientated' culture brought with it increasing impacts upon the planet that we inhabit. It is during this century that technology will have to be brought to bear, and used to resolve the problems that its development has created. These impacts on our planet, some irreversible, are numerous and include resource consumption, ozone depletion, species extinction, pollution and eutrophication.

Consider climate change as one example of an impact within the broader problem of sustainability, as it is an impact with which the majority are, at least in concept, familiar with. The greenhouse effect, caused by the build up of carbon dioxide (CO_2) in the atmosphere, is considered as one of the greatest environmental effects that man has had upon the planet, and that if current trends continue levels of CO_2 concentrations are certain to be reached that will dangerously interfere with global climate.[1] At the 1992 Earth Summit 154 states signed the Framework Convention on Climate Change, which includes the demand that signatory states stabilise greenhouse gas concentrations, '... at levels preventing a dangerous human interaction with the climate.'

The earth's atmosphere has a natural greenhouse effect, without it the average global temperature would be too low to support human life. However, human activity is significantly magnifying the extent of the natural greenhouse effect, to the point of raising the temperature of the planet. In the late 1980s, the Intergovernmental Panel on Climate Change (IPCC) was established to determine the implications of the perceived changes in climate. The IPCC suggest that to stabilise our climate would require reductions of greenhouse gas emissions in the region of 60 percent worldwide.[2] It is estimated that the period available for achieving this target is approximately 50 to 60 years.[3]

Parties to the United Nations Framework Convention on Climate Change (UNFCCC) held in Kyoto, during December 1995, adopted the Kyoto Protocol. This sets out targets for Europe to reduce its emissions of the six primary gases that cause climate change. This target is to cut emission by 8 percent below the levels of emission in 1990, by the period between 2008 and 2012. Evidently this is somewhat below the targets identified by the IPCC.

3.0 The Local Context

"The sum of the local at least equals the global" is a familiar phrase for those with an interest in sustainability, and the United Kingdom has a significant part to play in the global picture outlined above.

---

[1] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998.
[2] Intergovernmental Panel on Climate Change. *The IPCC Scientific Assessment*, Cambridge: Cambridge University Press, 1996.
[3] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. Op. Cit

Approximately 50 percent of the CO_2 emissions in the United Kingdom can be attributed to energy use in buildings, and 60 percent of this, or 30 percent of the total, can be attributed to the dwelling stock.[4] In addition, CO_2 accounts for around 87 percent of the relative contribution of the anthropogenic greenhouse gas emissions in the United Kingdom.[5] The level of domestic emission at present is approximately 157 million tonnes; the goal by the year 2010 is approximately 134 million tonnes.[6] Since the Kyoto Earth Summit, the Government in the United Kingdom committed itself to go beyond the demands of the Kyoto Protocol, setting the target of a 20 percent reduction of 1990 levels of domestic emissions by 2010.[7] This is still somewhat below the IPCC target of 60 percent reductions.

Evidently, to address these issues, remembering that the contribution to the greenhouse effect is but one of a wider range of impact considered here, rapid and significant inroads need to be made in improving the performance of the products of our national house builders.

4.0 The Consumer Product

The current products of the national housing providers, house builders and housing associations, are inefficient and wasteful examples of energy and resource profligacy. The inadequacy of these existing products can be demonstrated through an appraisal of the typical three bedroom semi-detached dwelling, which is taken as being representative of that product. The appraisal constituted a benchmark study of the performance of the dwelling against a set of predetermined headline criteria; these can then be contrasted with the performance of a dwelling by our European counterparts as a comparison for each of the criteria.

---

[4] Shorrock, L. D. *Future Energy Use and Carbon Dioxide Emissions for UK Housing: A Scenario*, Building Research Establishment, July 1994; and Department of the Environment, Transport and the Regions. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report Number 53*, London: HMSO, 1998.

[5] West, John, Carol Atkinson and Nigel Howard. 'Embodied Energy and Carbon Dioxide Emissions for Building Materials,' Paper presented at the CIB Task Group 8 conference on 'Environmental Assessment of Buildings,' 16-20 May 1994, at the Building Research Establishment.

[6] Department of the Environment, Transport and the Regions. *A Better Quality of Life - A Strategy for Sustainable Development for the UK*, London: HMSO, May 1999.

[7] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.

Criteria	T3B	European
CO_2 emissions during inhabitation ($kgCO_2.m^{-2}.a^{-1}$)	50.4	0
Density ($d.ha^{-1}$)	< 100	300
Design life-span (years)	60	120
Embodied energy ($kWh.m^{-2}$)	1,000	250
Embodied CO_2 ($kgCO_2.m^{-2}$)	360	90
Energy consumption during inhabitation ($kWh.m^{-2}.a^{-1}$)	194	32
Energy generation ($kWh.m^{-2}.a^{-1}$)	0	13
Potable water consumption ($l.p^{-1}.d^{-1}$)	160	0
Space standards (m^2 and m^3)	82, 197	104, 250
Thermal performance of the envelope – roof, wall ($W.m^{-2}.K^{-1}$)	0.25, 0.45	0.09, 0.14

Therefore, the current products of our national housing providers can be seen as inefficient and wasteful. At present they are unable to be a part of any drive toward a cessation of the destruction of the natural environment. Evidently they can be significantly improved upon, as demonstrated by one-off dwellings in the United Kingdom, and both one-off and volume building in Europe.

5.0 Construction Taskforce, Movement for Innovation and Construction Best Practice Programme

In July 1998 the Construction Task Force, chaired by Sir John Egan, published its report *Rethinking Construction.*[8] Its objectives were to propose improvements in cost, duration, quality, safety and performance for the construction industry, informed by experience of radical change and improvements in other industries. The Movement for Innovation (M^4I) and the Construction Best Practice Programme (CBPP) were both established with the specific intention of improving the performance of the construction industry, and explicitly within that the house building industry.

The M4I was specifically established with the aim to translate the ambitions set forth in *Rethinking Construction* into reality. The mission of the M^4I is to implement improvement in the construction industry in terms of value for money, profitability, reliability and respect for people. Its specific objectives in achieving this ambition are a 20 percent reduction in capital cost and construction period, 20 percent reduction in defects and accidents, a 10 percent

[8] Construction Task Force. *Rethinking Construction*, London: HMSO, July 1998.

increase in profitability, and a 20 percent increase in predictability of the performance of a project.[9]

The CBPP created a series of Key Performance Indicators (KPIs) against which to benchmark the performance of specific criteria within the construction industry and process. These would both act as drivers for change and monitor progress. The KPIs covered the following areas: construction cost, construction time, predictability both in terms of cost and time, productivity, profitability, defects, safety, and client satisfaction in terms of product and service.

The inadequacy of the existing products of the house building industry has been established above. Therefore it is now possible to consider to what extent the remit of the agendas of the M[4]I and CBPP are capable of implementing improvements in the performance of a dwelling which will address the urgent progress that is required in the environmental sustainability of the housing stock.

The criteria being addressed by both the M[4]I and CBPP can be collectively considered as: construction cost, construction duration, predictability, productivity, profitability, defects, safety, and client satisfaction in terms of product and service. As a comparison, other criteria could also be considered which have emerged as part of the current drive toward improving the performance of the dwelling. These have developed as key criteria from initiatives such as the Government's Millennium Community Competitions in Greenwich and Allerton Bywater and have, through research conducted by the author, emerged as among the most critical criteria in improving the ecological sustainability of a dwelling.[10] These are used in the comparison above between the typical dwelling produced by our national house builders and housing associations and current best European practice. They are: CO_2 emissions during inhabitation, density, design life-span, embodied energy, embodied CO_2, energy consumption during inhabitation, energy generation, potable water consumption, and thermal performance of the envelope.

In terms of determining the benefit to the environmental sustainability of the dwelling, improvements can be considered against four parameters of degradation. These are not all encompassing, but present a range of ecological impacts on the natural environment; they

---

[9] The Movement for Innovation website, 12 May 2000: www.m4i.org.uk

[10] Smith, Charlie. *Procuring the Urban House in Paradise*, on-going PhD thesis, Liverpool John Moores University.

are: the greenhouse effect, pollution emissions, natural resource depletion (which included species and habitat destruction), and ozone depletion.[11] The potential improvement in sustainability is considered as the contribution made to minimising the impact on each parameter by moving from the performance standard of the typical dwelling to that of the improved scenario for each of the criteria. In the case of the M⁴I and CBPP criteria, the scenario is given by the proposed benchmark improvements; in the case of the other criteria, these are determined by the change from the typical 3 bedroom semi-detached dwelling to the European standards outlined above.

If the benchmarked improvements in construction cost, construction duration, predictability, productivity, profitability, defects, safety, and client satisfaction are achieved, it is self-evident that none will have any direct and significant beneficial effect in reducing the impact of a dwelling on the parameters of degradation. Thus it can be concluded that at present the M⁴I and CBPP criteria are unable to be a part of any drive toward a cessation of the destruction of the natural environment; whereas there are other criteria, all capable of being benchmarked, that are eminently suitable for this purpose. This critique demonstrates an inadequacy of the scope of the M⁴I and CBPP criteria in improving the current product of the house building industry to address the increasingly significant determinants of sustainability. Neglecting such crucial areas as energy consumption and emissions could therefore be construed as a significant shortcoming of the M⁴I and CBPP agendas, particularly if their *raison d'etre* is understood as to improve the performance of our built environment.

However, this is not to say that in their present form they should address such issues, but to demonstrate that currently they are an incomplete set of criteria when considering the concept of improving the performance of our house building industry in a wider perspective. Also that to create such a holistic set will require the addition of prudently selected performance criteria. The challenge thus becomes to establish a more holistic set of criteria against which to benchmark the performance of the dwelling, which encompass a response to the wider agenda.

What should these criteria be? At present the Building Regulations are the only mandatory requirements that set down the performance of a dwelling, and this is limited to the thermal performance of the fabric. In the commercial sector this has actually contributed to a

[11] These criteria are selected from those used for the Dobris Assessment, a report on the state of the pan-European environment: Stanners, David and Philippe Bourdeau (eds). *Europe's Environment – The Dobris Assessment*, Cambridge: European Environment Agency, 1995.

negative effect; the dramatic rise in energy consumption through mechanical air-conditioning was able to arise because of the exclusive focus upon envelope U-values.[12] In terms of voluntary benchmarking, this also exists in partial format. One of the most recognised environmental performance assessments for buildings are the Building Research Establishment's *Environmental Assessment Models* (BREEAM), the most recent reissue of the version for dwellings is *EcoHomes*, published last April.[13] These offer a limited set of quantitative parameters in terms of improving the environmental sustainability of a dwelling, such as carbon dioxide emissions, thermal performance, low nitrogen oxide emissions. However, this assessment does have its shortcomings. For example the focus upon CO_2 emissions without energy consumption means that a larger amount of energy of a fuel with a lower carbon content could be used; this would have a detrimental effect in ways not accounted for by the *EcoHomes* criteria, such as the consumption of natural resources.

The criteria used in the comparison between the typical product of our housing providers and European best practice evidently lend themselves to defining the environmental performance of a dwelling, and as stated have emerged as among the most critical criteria in improving the ecological sustainability of a dwelling. As an exercise in determining which of these have the most benefit in reducing the ecological impact of the dwelling, they were subject to a process of prioritisation. This aimed to determine their relative significance to improve the overall ecological sustainability of the dwelling, and therefore provide a potential structure for adding criteria to those already being used by M⁴I and CBPP.

The improvement in performance was taken as moving from the standard of the typical three bedroom semi-detached dwelling to that of a best practice European dwelling, as given above, which has been proven as technically feasible. For each of the criteria, the improvement in performance was measured in terms of its contribution to reducing the effects of the four parameters of greenhouse gas emissions, pollution emissions, natural resource depletion and ozone depleting emissions. For example, in the case of energy consumption during the period of inhabitation, the amount of energy saved by moving from 194 to 32 $kWh.m^{-2}.a^{-1}$ for a typical dwelling of 84 m^2 was calculated. It was then determined what this saving would contribute to the reduction in carbon dioxide and methane emissions, the emissions of pollutants, the consumption of fossil fuels, and the emission of ozone depleting gases. This process was carried out for each of the criteria, and the contributions

[12] Lowe, Robert. 'Defining and Meeting the Carbon Constraints of the 21st Century', *Building Research & Information*, March 2000.

under each parameter converted into directly comparable units, such as $kgCO_2$ per annum equivalent for reduction in greenhouse gas emissions.

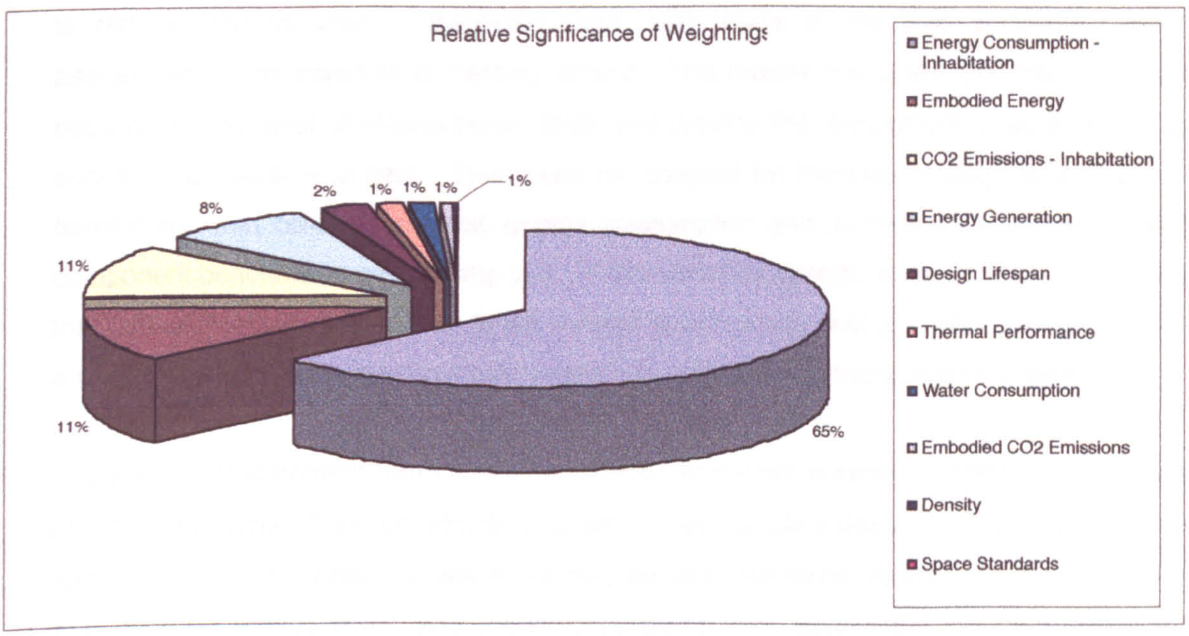
These quantitative values were then converted into a normalised ratio of each other. This was done to make the contributions for the different parameters more comparable. The methodology is adapted from the Analytic Hierarchy Process (AHP).[14] For each parameter the values the contribution of all the criteria are summed to provide an overall total of the reduction in impact on that parameter; the contribution for each individual criterion under that parameter is then divided by the total. Therefore the total of the weightings under each parameter sum to equal one. This provides a weighting for each of the criteria, in terms of its relative contribution to reducing the impact on that parameter, for each of the four parameters, which is a ratio out of one. By adding the weightings for each of the criteria across the four parameters an overall normalised weighting for a specific criterion can be determined. The results of this process are given in the table below, ordered with the highest weighting first.

Criteria	**Weighting**
Energy consumption - inhabitation ($kWh.m^{-2}.a^{-1}$)	2.328
Embodied energy ($kWh.m^{-2}$)	0.411
CO_2 emissions - inhabitation ($kgCO_2.m^{-2}.a^{-1}$)	0.388
Energy generation ($kWh.m^{-2}.a^{-1}$)	0.295
Design life-span (years)	0.091
Thermal performance ($W.m^{-2}.K^{-1}$)	0.049
Potable water consumption ($l.p^{-1}.d^{-1}$)	0.048
Embodied CO_2 ($kgCO_2.m^{-2}$)	0.021
Density ($d.ha^{-1}$)	0.012
Space standards (m^2/m^3)	- 0.129

What the weightings are able to demonstrate is not only the most significant of the criteria in reducing the environmental impact of the dwelling, as assessed against the four parameters,

[13] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, April 2000.
[14] Wedley, William C. 'The Analytic Hierarchy Process,' *Socio-Economic Planning Science*, January 1990.

but also the relative significance of the criteria to each other. For example, and probably most worthy of note, is that the most significant, the energy consumed during the life span of the dwelling, has a weighting over five times that of the next most significant, the embodied energy of the dwelling. The relative proportions of these criteria can be visually represented in a pie chart.



Therefore, this would suggest that as an expansion of the existing M[4]I and CBPP criteria, or a complementary set, the above should be considered as significant, and their relative weightings used to inform the priority to be given to achieving established benchmarks. In addition, specific emphasis should be placed upon achieving significant reductions in the energy consumed by the dwelling during its period of inhabitation, as this will, in relative terms, have by far the greatest benefit on the ecological sustainability of the dwelling.

6.0 Value for Money

If we are unable to break 'cost-orientated' thinking, there are potential links that could be made between the agenda of the M[4]I and CBPP and the wider agenda of sustainability. An example of how such a synthesis might be achieved is given by lifecycle costs, which at one time was a part of the M[4]I agenda. Benchmarking a reduced lifecycle, as well as construction, cost would place emphasis on reducing the energy costs of the building, through reducing energy consumption. Also reducing maintenance costs could be achieved by increasing the life span of the dwelling's components, with a consequent increase in the efficiency of natural resource use.

That is not to say that cost should lead environmental performance, but that it may provide a route through which to implement improved environmental performance by providing trade-offs between reduced construction costs to increase specification and performance in order to reduce lifecycle costs. Raymond Cole, who works in the field of environmental assessment, is an advocate of 'nesting' criteria. This means that a few key criteria have a second or third level of criteria below them that provide the mechanism through which to achieve the headline targets. This could be adopted for lifecycle costing as a headline benchmark, with construction cost, energy consumption and maintenance as inter-related component benchmarks contributing to it. There would be specific energy targets to achieve that overall lifecycle benchmark. In the context of increasing energy costs, this would force a progressive decrease in energy consumption in order to continually meet the target.

However, in procurement terms there are specific problems in terms of implementing focus on lifecycle rather than construction costs. This is particularly the case for private speculative house builders, where there may be little perceived added value to a property with very low energy costs, and therefore consumption. Speculative house builders are market led beasts, and claim that at present there is little demand to reduce energy consumption of the dwelling.[15] This is an example of a contrast between the house building industry and the car manufacturing industry. Few, if any, car manufacturers would provide specification details for a customer without including the energy consumption of the vehicle, which is a highly performance driven product. This is in sharp contrast to the specifications typically provided for new dwellings that rarely, if ever, include details of likely energy consumption, although the *Standard Assessment Procedure* (SAP rating) was allegedly supposed to provide a mechanism for this.

Public sector housing might be more likely to perceive benefit in reducing lifecycle costs due to the long-term involvement of resident social landlords. Reducing energy costs through minimising consumption will mean that tenants have a reduced financial burden, and reducing the amount of maintenance required to a dwelling, and energy and resources embodied within that maintenance would also reduce lifecycle costs.

---

[15] Burns, Mark. *Toward a Mass Market for Sustainable Housing*, unpublished dissertation thesis, Liverpool John Moores University, 2000.

7.0 Community

Of course sustainability encompasses not only ecological issues, there are also societal and economic spheres. These issues could also be addressed through widening the scope of benchmarked criteria. For example, benchmarking programmatic diversity of a housing development would create an impetus for increasing community facilities and foci, rather than creating mono-functional housing estates; this would also have the added benefit of reducing transport by car.

Also, emphasis placed on reducing energy consumption, with consequent emissions, would reduce energy bills, and therefore provide owners or tenants with more disposable income. Across the life span of the dwelling this cost saving can be significantly more than the increased construction costs. For example, if a typical annual energy consumption bill, therefore excluding standing charges, for a three bedroom semi-detached is £372 per annum;[16] if the energy consumption were reduced to 16.5 percent of that, as in the European precedent given above, the energy costs would be reduced to £61.38 per annum. Even ignoring fuel cost increases, across the life of the dwelling[17] this would equate to a cost saving in energy bills of £18,637.20. Across the area of the dwelling, taken as 84 m^2, this would be profitable if the additional construction costs were less than 221.74 £/m^2! Even across the typical ownership period of a dwelling of 5 years, this would equate to a total energy consumption bill saving of £1,553.10, or 18.48 £/m^2. This increase in disposable income of £310.62 per annum will help to contribute to the overall sustainability of the dwelling's inhabitants both in terms of economic and social inclusion, in addition to the environmental sustainability of the dwelling itself.

8.0 Conclusion - Overall Sustainability

To return to the issue of carbon dioxide emissions and global warming, by way of example, to what extent can new and refurbished dwellings contribute to improving global sustainability? It has been suggested that in developed countries significant improvements need to be made to the environmental impact of our actions even just to halt the trend of climate change. To achieve an immediate stabilised level of CO_2 at the current level, the IPCC advocate a 60 percent reduction in emissions. It is estimated that this would have to

[16] This value is based on empirical research of domestic fuel bills in three bedroom semi-detached dwellings built to 1995 Building Regulation standards.

be furthered to 80 percent by 2050, falling to zero emissions, to outweigh the effects of stabilisation of the carbon gradient in seawater and net oceanic absorption.[18]

Clearly this is an arduous prospect, but has been demonstrated as technically achievable in this country. In their house in Southwell, Nottingham, Robert and Brenda Vale's house reduced CO_2 emissions by 80 percent of that of a typical three bedroom semi-detached. But what part could agendas such as the M[4]I and CBPP play in achieving this? One would be that the agenda of the M[4]I and CBPP is expanded to embrace an urgent drive toward more sustainable housing. These programmes provide an opportunity to integrate a more holistic series of criteria into existing mechanisms.

In some ways, it is short-sighted of the Government not to implement frameworks in which to reduce the environmental impact of housing which, as demonstrated at the start of this paper, contributes 30 percent of country's CO_2 emissions. Such action could provide a significant contribution to achieving the Kyoto, even if not the IPCC, targets. Whilst issues of sustainability have been present in a number of government initiatives for improving the housing industry, such as the Millennium Community competitions at Greenwich Allerton Bywater, these have never been formalised into a framework such the KPIs. However, some are related to the Government's objectives put forward in *A Better Quality of Life*, which is their strategy toward improving the sustainability of the United Kingdom in general. Integrating these criteria into programmes such as M[4]I and the CBPP would provide one way in which to achieve the targets proposed.

This would be an opportunity to create a more extensive notion of 'joined-up thinking'. For example, if one assumes that the 20 percent reduction in capital costs is as measured against a directly comparable specification, this cost saving could be re-directed, through quantitative benchmarking, toward improving the environmental sustainability of the dwelling. This would provide a route through which to finance energy saving strategies such as increased thermal performance, increased air-tightness of the dwelling's fabric, and more efficient heating systems.

---

[17] The life span of the dwelling is taken as 60 years. This is the value for the minimum design life span of new dwellings under current British Standards, and is the baseline benchmark used by the Building Research Establishment.

[18] Lowe, Robert. 'Defining and Meeting the Carbon Constraints of the 21st Century', *Building Research & Information*, Volume 28 Number 3, 2000.

Evidently there should be an increase in the significance of the environmental profile of dwellings. Rather than masking sustainable performance criteria under a generalised heading of lifecycle costs, although they will have consequent cost savings across the life span of the dwelling, it is proposed that there should be an established series of benchmarked criteria. Ideally these would be integral, or as a complementary set, to those of the M[4]I and CBPP. These should identify the dwelling's performance in terms of, at least, energy consumption during inhabitation, embodied energy, CO_2 emissions during inhabitation, energy generation, design life-span, thermal performance, potable water consumption, embodied CO_2 emissions, density and recyclability. The outcome of this process would be a holistic, more comprehensive, series of benchmarked performance criteria that could be implemented through mechanisms such as M[4]I and CBPP. This should be a part of a process to make such criteria a specific part of the headline agenda for improving the performance, in all senses of the concept, of our housing industry.

7.2 Procuring Innovation in Housing

Abstract

This paper will discuss issues and implications on procurement strategies for achieving innovation in the design and performance of new housing, and will compare and contrast recent strategies to procure innovative housing.

Reference will be made to specific examples, with significant input from the experiences of the author in the procurement and evolution of the polemical project for the second Millennium Community competition at Allerton Bywater. These present different alternatives in procurement strategies, and the advantages and disadvantages of each will be discussed.

Key Words

Innovation, Millennium Community Competition, performance, procurement

1.0 Introduction

Housing policy and procurement methods require to comprehensively change. There is no discernible improvement in what is being offered consumers:

* because of demonstrable excessive wastage and inefficiencies from land use to construction methods,
* because of energy profligacy especially during the period of inhabitation,
* because of the absence of community life within housing areas,
* because of a lack of adaptability of houses to meet material change,
* and because of an overarching lack of value for money.

These five areas of concern suggest an absence of short and mid-term ecological, economic and social sustainability.

In order to address this need for change, accent on costs being the sole arbiter of decision making needs to give way to value being placed on a wider agenda of items, land needs to be more efficiently used, and behaviour of policy makers and housing providers needs to radically adapt. Such changes will be achieved through community-led housing practices, a massive increase in practical research and development, acknowledgement that improvements will only emerge through design time, a methodological setting and monitoring of benchmarks, and the creation of new types of policy organisms and provider companies.

This paper addresses one aspect of this need for change, namely why and how the procurement of our housing, by both private and public sectors, can and should be changed in an effort to improve their performance throughout the procurement process, and then into their inhabitation.

2.0 The Current Product

One might ask, "Why is there a need to procure innovation in housing?" Or in a more colloquial manner, "If it is not broken, why fix it?" The accompanying paper 'Construction Task Force, Movement for Innovation and Construction Best Practice Programme: Relevance and Appropriateness to Innovation in a Wider Context' demonstrates the inadequacy of the dwellings that are currently produced by our national house builders and housing associations. They are wasteful and inefficient both in their construction and then during their inhabitation. In their construction they make inefficient use of land, a natural resource, through low housing densities, and use high levels of embodied energy to extract, produce and assemble, and make inefficient use of, materials and components. They are wasteful in construction, with approximately 10 percent of the materials delivered to site ending up as waste,[19] making further inefficient use of materials, and therefore natural resources. During inhabitation they consume a large quantity of fossil fuels, in comparison to what could be achieved, and is achieved by our Scandinavian counterparts, which has the consequence of high levels of pollution and carbon dioxide emissions.

Yet the poor performance of our current new housing is evident not only in their environmental performance. Research shows that they are small in terms of their space standards against almost all of our European counterparts, in terms of square metres per person.[20] This trend has been continual since the demise of the impact of the Parker Morris standards. Other research shows that this is particularly the case for speculative private developments, in which the space standards are worse than those in public sector housing.[21] Equally, prices per square metre are higher in England than in any of our north European national neighbours.

In colloquial parlance, "It is broken, we need to fix it."

In *Rethinking Construction*, the report of the Construction Task Force, published in July 1998, principles are put forward for alternative procurement strategies, as opposed to competitive tendering, to produce best value and innovation in the construction industry, and with specific reference to housing.[22] The principal criticisms of competitive tendering by the Task Force are of its focus towards lowest initial price, and its lack of ability to differentiate between lowest price and *best value*; also, they perceive competitive tendering as conducive to the fragmentation and adversarial nature of the United Kingdom construction industry.

Evidently, in terms of the shortcomings identified above, there are inadequacies in the methods by which housing is currently procured. The virtually exclusive focus on

---

[19] Skoyles, E. R. and John R. Skoyles. *Waste Prevention on Site*, London: Mitchell, 1987.
[20] Kaplanis, Peter. *Space Standards: International Tendencies Since 1945*, unpublished dissertation, Liverpool John Moores University, 1999.
[21] Smith, Charlie. *Procuring the Urban House in Paradise*, on-going PhD thesis, Liverpool John Moores University.
[22] The Construction Task Force. *Rethinking Construction*, London: HMSO, 1998.

construction cost, which is translated into purchase cost or rental levels, equates to poor value in its wider sense for the purchaser or tenant. Typically she or he will be offered a defect-ridden product, cramped in terms of internal space provision, that is built to the minimum levels of energy efficiency and thermal performance as set down by regulatory standards. New procurement strategies need to be adopted that orientate focus away from solely cost, and toward *best value* for the consumer, in all senses of the term.

3.0 Allerton Bywater

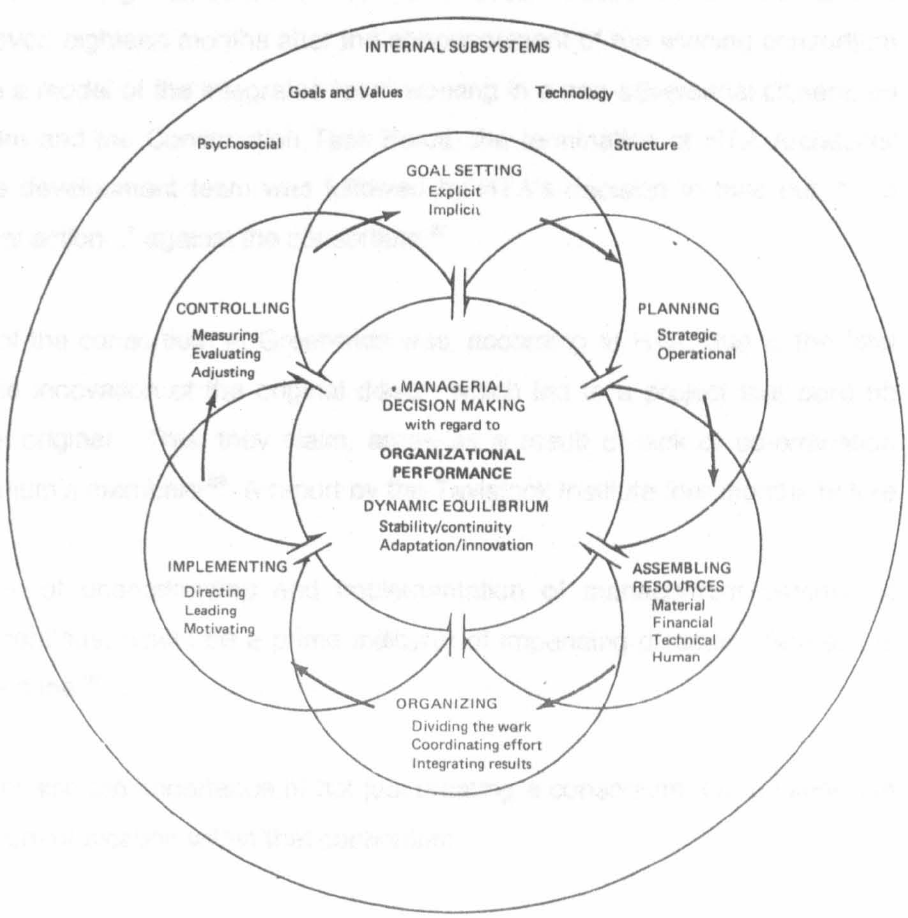
The Millennium Community competitions, run by English Partnerships, are one vehicle that intended to foster more integrated team approaches to innovation in the design, construction and realisation of high quality housing and mixed function projects. This so-called 'joined-up thinking' was to demonstrate models that have healed the fragmentation between the different parties within the construction industry. These were procured through consortium submissions to design-led competitions. It was a specific demand that consortia submitting for the Allerton Bywater Millennium Community competition include a national house builder from the outset; this would appear to have been an attempt to encourage innovation in a section of the construction industry frequently unwilling to acknowledge, let alone embrace, it.

Included within the report of the Construction Task Force is the proposed introduction of performance measurement against clear targets for improvement, in particular in terms of quality, time and cost. It is benchmarking that provides the route to measuring projects against these, and other, targets. The Stage Two Development Brief for the Allerton Bywater competition also used benchmarks in defining performance standards of the dwellings that were to be proposed by the consortia. These included 50 percent reduction in energy consumption, 50 percent reduction in household waste, 30 percent reduction in construction cost, 25 percent reduction in construction time, and zero defects at hand over.[23] The key benchmarks that were then proposed by the winning consortium, the Aire Regeneration Partnership, in addition to those demanded by English Partnerships such as the construction cost benchmark, were built in to the Heads of Terms Agreement to ensure their delivery.

The avocation of the increased development of a team approach to a project, or a series of projects, through a process that utilises the full construction team in *Rethinking Construction*[24] has a precedent in the contemporary management philosophy of Total Quality Management (TQM):

> ... which seeks to control value creation through clear working relationships between the various specialists within the value system.[25]

In terms of a link between TQM and procurement, Kast and Rosenzweig's definition of internal field presents a model that, as a way of improving communication and transparency, might epitomise the relationships envisaged by the Construction Task Force.



Internal Subsystems as a model for communication within a team
from, Kast, F. and J. Rosenzweig. *Organisation & Management*, McGraw-Hill, 1985, p. 402.

---

[23] English Partnerships. *Millennium Communities Competition - Allerton Bywater Stage Two Development Brief*, 1998.
[24] The Construction Task Force. Op cit., p. 21.
[25] Johnson, Gerry and Kevan Scholes. *Exploring Corporate Strategy*, London: Prentice Hall, 1993, p. 134.

The Greenwich Millennium Village, the first of the Millennium Community competitions, was won in February 1998 by a consortium led by developers Countryside Properties and Taylor Woodrow with the Swedish architect Ralph Erskine and British practice HTA Architects leading the masterplanning. It was also intended as a model for the procurement of innovative new urban housing design and construction. The consortium approach, fostered by the Millennium Community competitions, was intended to create a more integrated team, with increased transparency between its members throughout the evolution of the project.

During the project's initial development the Greenwich team displayed the signs of an integrated approach, including members of the contractor's team based in the offices of HTA Architects.[26] However, eighteen months after the announcement of the winning consortium it had ceased to be a model of the integrated team working in a non-adversarial climate, as espoused by Latham and the Construction Task Force; the termination of HTA Architects' appointment by the development team was followed by HTA's decision to take out, "... a very substantial legal action..." against the consortium.[27]

The disintegration of the consortium at Greenwich was, according to HTA, due to the fatal compromising of the innovation of the original design which led to a project that bore no resemblance to the original. This, they claim, arose as a result of lack of co-ordination between the consortium's members.[28] A report by the Tavistock Institute four months before said of the project,

> Such a lack of understanding and implementation of management process, if allowed to continue, would be a prime indicator of impending disaster. Something needs to be done.[29]

This serves to emphasise the importance of not just creating a consortium, but creating the right structure and communication within that consortium.

The lack of understanding by some members of the team has also caused problems in the procurement at Allerton Bywater. Having won the competition the design team were under

---

[26] From interview with Richard Hodgkinson of Taylor Woodrow, at the offices of HTA Architects on 12 October 1998.
[27] Slavid, Ruth. 'Developer Sacks HTA in Millennium Village Chaos,' *The Architects Journal*, 1 July 1999.
[28] Architects in Housing Website, 11 July 1999: www.aih.org.uk
[29] Slavid, Ruth. 'RIBA: Erskine Should Resign Too,' *The Architects Journal*, 8 July 1999.

constant pressure from the house builders to revise the masterplan in a manner that would be detrimental to some of its fundamental principles, to the extent that the design team repeatedly felt forced to consider their future in the project. Whilst negative opinion can be as much assistance to the evolution of a project as positive, it is considered that the house builders have provided only one beneficial contribution to the project's evolution, which was to encourage a further diversity of dwelling types, from twelve to thirty. The reason for this was based purely on the desire to widen the potential market targets, so as to increase the potential sales.

An advantage of the development brief based consortium competition is that they can be used to procure excellence in design quality, as well as performance standards. However, as noted in the Urban Task Force report, *Towards An Urban Renaissance*, whilst competitions are becoming increasingly used for high profile projects, there is still some way to go to transform the culture of the development industry, particularly the volume housing sector.[30] The Task Force also observed the way that in other European countries competitions are used as a mechanism to test innovative urban design approaches.

There will, of course, be a cost and time implication in the use of competition. The Urban Task Force emphasise the need to allow sufficient time for the development of an appropriate and rigorous brief that communicates explicitly the aims and objectives, and for competitors to develop robust solutions; this, they expect, could vary from three to twelve months. The importance of composing an appropriate calibre of assessment panel, to both draw a high level of entry from participants and to guarantee the selection of a high quality solution, is also emphasised. An approximate value for the cost of the competition process is proposed as at least up to half a percent of the total build costs.

A potential disadvantage of the consortium approach is that, whilst it may contribute to a higher quality of design and innovation, it may also lead to a loss of cost control over other procurement routes. Because the team is constructed at a very early stage, to ensure that all parties can participate in the development of the design, the opportunity for cost-based competition could be lost. This aspect was overcome in the Allerton Bywater project by the inclusion of a maximum build cost benchmark in the Terms of Agreement.

---

[30] Urban Task Force. *Towards an Urban Renaissance - Final Report of the Urban Task Force*, London: E & F N Spon, 1999.
[31] Ibid., p. 35.

However, in March 2000, approximately one year after the competition was one, English Partnerships felt forced to wrest control of the Allerton Bywater project back from the house builders and to assume control of the project. This resulted in a significant reduction in the role of the house builders in the project. Rather than being responsible for delivering the whole project, the house builders would only deliver the housing component, with the mixed-use elements, a central part of the project, being procured independently through English Partnerships. This was a major turn around from the original brief. Aire Design, the architects of the competition entry, were then employed directly by English Partnerships to oversee the delivery of the masterplan and its original aspirations, and by the house builders over the delivery, in part, of the housing. Executive architects were employed to assist in delivering the housing. This strategic change to the project, as at Greenwich, places everyone involved on the back foot!

The lessons being learnt is that the promoters of such competitions, in this case English Partnerships, must maintain a strong grip on the whole process, while the involvement of national house builders will no longer be a necessary prerequisite.

4.0 Performance Specification

Another point that can be gleaned from the experiences of the Millennium Community Competitions is that one of the potential procurement routes through which to influence innovation in construction would be through the use of performance specifications. The increasing scope of benchmark performance indicators could be expanded, in line with suggestions made in the paper 'Construction Task Force, Movement for Innovation and Construction Best Practice Programme: Relevance and Appropriateness to Innovation in a Wider Context', and be built into the procurement strategy. This could be client led, placing demands on the design and construction partners. Benchmarking performance could also be part of a regulatory drive, as a consequence of Government initiatives to achieve its reduction targets for carbon dioxide emissions, placing more stringent demands on energy consumption by new and refurbished dwellings, therefore placing an onus upon the whole team.

5.0 Risk

In a sense procurement, especially when innovative, is essentially the apportioning of risk. Since the visionary architect Le Corbusier drew a comparison between the automotive industry and architecture, notably in *Vers une Architecture* first published in 1923, the similarities and differences of these two fields have frequently been cited. Perhaps in terms of procuring innovation in housing, the comparison should be made with motor car rally or racing teams.

For example Formula One, as with other such teams, demands a holistic team contribution at the highest standard of performance and innovation. However, risk and responsibility are shared within the team. Should the gearbox fail, the driver does not sue the mechanics, and should the driver crash the car on the first lap, the team owner does not take him to court over negligence or lack of due diligence, although he might not employ him next season. Perhaps the important point to draw from this somewhat light-hearted analogy, is that each member of the Formula One team is working as a singular individual toward a shared goal, and not the maximum profit for their particular section of the team. It is the underlying attitudes of all parties involved that are crucial.

A sharing of risk throughout the team might also be reflected in the dispersion of profit, rather than fee-based payment to consultants and contract payments to builders. Why would an architect undertake significant exposure to risk in order to radically cut construction cost and duration on a traditional percentage-based fee? To recall Kast and Rosenzweig's diagram, each member within the internal field would have a stake in the profit of the project proportional to the risk that they undertake.

6.0 A Market for Innovation?

A question that does arise is where the most likely market for innovation may lie? If public sector, speculative housing for purchase or the private rented sector? Opinion on this issue has differed.

The Construction Task Force state that it is their belief that the initial opportunities for improvement in the performance of house building actually exist within the public sector, which would lead to an interchange of innovation between the public and private sectors, for the critical reason of scale. A minority of major clients commission the majority of social housing. Housing associations are the dominant providers of new social housing; in 1998/99 there were projects for 30,000 homes, 50% of which is accounted for by 60 housing associations[31]

However in contrast, Richard Best, director of the Joseph Rowntree Foundation who sponsor significant research into house building, perceives that innovation in house building is unlikely to occur within housing association projects, due to pressure from lenders and the National House Builders' Council (NHBC). He also believes that innovation is unlikely to originate from traditional house builders, as they tend to operate within very conservative markets. Instead Best advocates the private-rented sector as being the most likely market in which innovation will occur as, with no accountability for public subsidy, it has freedom in which to draw in innovative ideas, techniques and technologies.[32] Worthy of note is that, whilst one favours public and the other private, both advocate the rental sector as the potential field for innovation, and neither identify the owner-occupied market as the likely best world for change. This is in contrast to Allerton Bywater, in which the dwellings are predominantly private sector speculative houses for sale; it was a specific intention of the design team to innovate to the same degree across both private and public dwellings, as well as in both housing and commercial sectors.

Roy Marshall, a senior manager of the Japanese construction company Kajima, perceives that the rental sector and private finance could provide stability during periods of recession. This relates to the Danish experience of the need to maintain a consistent market of production during innovation in prefabrication and standardisation technologies.[33]

To innovate successfully, it is often necessary to adjust the context of a procurement strategy. Ezra D. Ehrenkrantz, of the New Jersey Institute of Technology in Newark, America, in a paper entitled *Procurement and Innovation - Some Successful Strategies*[34] identified that the procurement of innovation was related to both the size of the market and the time available for innovation. If a procurement strategy is structured so that a significant amount of time is available at the early stages of the project, a large amount of research and development can take place; however, the market itself will have to be of sufficient scale to facilitate amortising that research and development. This point reflects the Construction

---

[32] Bazlinton, Chris and Ken Bartlett. *Rethinking Housebuilding*, York: York Publishing Services Limited, 1997.
[33] Ibid., p. 56.
[34] Davidson, Professor Colin H. (ed). *Procurement - The Way Forward*, IF Research Corporation, 1998, p. 17.

Task Force's perception that innovation may best occur in the social sector, due to the small number of large clients, with a large market share:

> ... if we are working with relatively small markets, and even if we have a lot of time available, to ask for high levels of innovation will not lead to success, because that market will not permit amortising the investment required for innovation.[35]

Certainly in the public sector, the Housing Corporation are using the power of its allocation of funding to encourage innovation. An increasing percentage of its funding has been set aside for projects that are a demonstration of the Egan principles. In addition, they have recently announced that £80 million of funding over the next two years, more than 7.5 percent of its programme, is to be awarded to projects that use prefabrication technology. This is a move to directly assist the implementation of recommendations in *Rethinking Construction*. In terms of the issue as to whether the public or private rented sectors may be most suitable for developing innovation, the directing of funding from the Housing Corporation could prove to be the impetus to create a more likely market for innovation in the social rented sector. In the Murray Grove Housing, London, by Cartwright Pickard for the Peabody Trust Housing Association, innovative volumetric prefabrication technology was transferred from other building types to public sector housing.

7.0 Value for Money

Economies of scale as a way of levering in innovation has important, but not crucial relevance, given the flexibility of construction prefabrication technologies.

The issue of scale is, potentially, of particular importance in the context of considerations of innovation in terms of partnerships and standardisation. For example, the Japanese house building industry is frequently cited as a precedent for innovation in partnering, standardisation and open building systems. The Japanese construction industry in general have already established a model of partnerships between designers, construction managers and suppliers; this process of partnering, in contrast to the fragmented and adversarial nature of the British construction industry is strongly advocated by the Construction Task Force.[36] When drawing comparisons with the Japanese house building industry, one should bear in mind that the production of the fifth largest Japanese house builder is approximately equal to that of the entire United Kingdom house building industry.

---

[35] Ibid., p. 18.

In Denmark, where the construction industry is arguably the leader in best practice of prefabrication and standardisation, experience has demonstrated that industrialisation requires organising the market and securing continuous sales.[37]

The Construction Task Force are aware that in the social housing sector, demand by housing associations and local authorities is affected by, " ... uncertainties and inefficiencies resulting from periodic changes in policy, direction and unpredictable levels of investment."[38] If, as the Task Force imply, initial opportunities for innovation in the house building industry exist in the social market, this must be seen in the context of its unpredictable nature, and the Danish experience of the need for an organised market and continuity of production.

There is a link here to the Allerton Bywater project, in which the number of dwellings proposed, approximately 550,[39] was used as a way of levering in larger space standards in terms of both area and volume, and also of a way of improving the environmental performance of the dwelling. This was achieved using the cost savings made through rationalised, standardised prefabrication techniques across the relatively large number of dwellings proposed to improve the thermal performance and air tightness of the dwelling, and to provide a larger volume and area of dwelling than is typical both of speculative house builders and housing associations.

The use of standardisation and prefabrication had other advantages than re-channelling cost savings, including significant reductions in construction duration. It was envisaged that the on-site production rate would be 300 percent that of a traditional speculative housing developer. Also, because standardised prefabrication in a factory controlled, precision environment can reduce the incidence of waste, and therefore help save on natural resources, it is to be used to cut construction waste by 50 percent, as benchmarked in the Heads of Terms.

Of course, in the scale of the production of a national house builder, 550 units is not large, and this demonstrates the application potential for changing the procurement strategies of national house builders if they were willing to adopt prefabrication on a significant scale.

---

[36] The Construction Task Force. Op cit., p. 12.
[37] Kjeldsen, Marius. *Industrialised housing In Denmark 1965-76*, Copenhagen: Byggecentrum, 1976, p. 10.
[38] The Construction Task Force. Op cit., p. 35.
[39] In the rationalisation of the masterplan, primarily due to pressure from developers, the number of dwellings was reduced from 688 to 550, mostly with the reduction of the number of lofts.

This may come in time, as Wimpey Homes, who completed 12,870 units in 1998, are currently experimenting with the prefabrication of one of their standard house types.

However, in order to procure the identified changes that are necessary to the products of our housing providers, the benefits of such moves would still have to be passed on to the consumer in terms of a more spacious and more efficient dwelling, rather than an increase in profit margins.

8.0 Conclusions

The experience of both authors during the Allerton Bywater Millennium Community competition is that to innovate successfully there needs to be adequate time built into the procurement strategy, and that there needs to be adequate time allowed for the development of that innovation if it is to be successful. This latter point is of particular relevance now that the drivers for innovation are coming from directions other than being client led, as was the case at Allerton Bywater, where the house builder should have been funding the innovations required by the brief, set by English Partnerships.

It is clear that innovation requires an increased design period. Therefore the procurement strategy must be one that facilitates this. Also, members of the design and construction team working together from the earliest possible stages can best achieve innovation; an example of this is the need to improve the air-tightness of the dwelling, which can have significant benefits in reducing the energy consumed in the dwelling during inhabitation. The achievement of a reduction in infiltration requires both a high standard of detailing by the designer and a high standard of construction quality to execute that detailing, that would have to come from an understanding of the principles and need for air-tightness. By working with a contractor at an early stage, the importance of quality in achieving such a benchmark can be communicated, but more importantly, the contractor can either assist in providing input into the construction techniques that may best achieve the target, or become aware that they may not be able to work within such demands, and fall out to be replaced at an early stage.

If projects require front-loading of the programme in order to allow innovation to develop, there will have to be a degree of desire, or at least acceptance, on the part of the client to allow this to be built into the procurement strategy. The Construction Task Force members were of the opinion that the direction and impetus for change and innovation in the United

Kingdom construction industry must be directed from major clients, and ask that industry join with major clients in order to achieve their radical proposals to change the way in which buildings are realised. Within the stolid environment of the speculative house building market, which represents the majority of new housing starts in this country, there is a reluctance to take up issues of innovation, particularly with respect to those that improve the environmental performance of the dwelling, which could, on the wider scale, be perceived as the most pressing. To place the impetus on the client in this sense would require either a major demand from the purchasers, or innovation within legislation such as the Building Regulations.

There is potential within development of a strategy for a holistic benchmarking of the required performance of both new build and refurbished housing to generate innovation in both the regulatory-led and client-led scenarios.

There will be benefit in creating a mechanism that retains an 'interest' of the members of the design and construction team in the post-completion performance of the dwelling. This is when it will be determined whether or not a significant proportion of the benchmarks, such as air-tightness and energy consumption during inhabitation, have been achieved. Ideally this will in a manner that does not engender an adversarial climate between those parties, and does not, therefore, add significant cost increases due to a perceived increase in risk liability. In theory, if members of the team are brought together earlier, they have an increased opportunity to achieve the specified demands, and therefore reduce risk. Ideally the opposite would be the case, where all members in the procurement process would share in the profit of the project, and therefore create an incentive to innovate successfully.

The turbulent evolution of the Greenwich Millennium Village and the consistent pressures from the house builders felt by the design team at Allerton Bywater both demonstrate the need for further clarity in communication and transparency between the parties involved, even in a consortium based environment. In particular a relinquishing of profit centred thinking on the part of the housing providers is needed to embrace a wider concept of value. From that can follow a re-channelling of cost savings from innovation in construction technology to increase value for the consumer, and also raising the awareness of lifecycle impact, such as using cost savings to increase energy efficiency and reduce consumption, and therefore have a global benefit.

To fix what is broken, requires a strategic triangle of relationships: the advocacy and implementation of forward planning; risk released housing providers and financiers; and alert and demanding consumers. Only then will housing in Britain move beyond the wasteful mediocrity that it represents today.