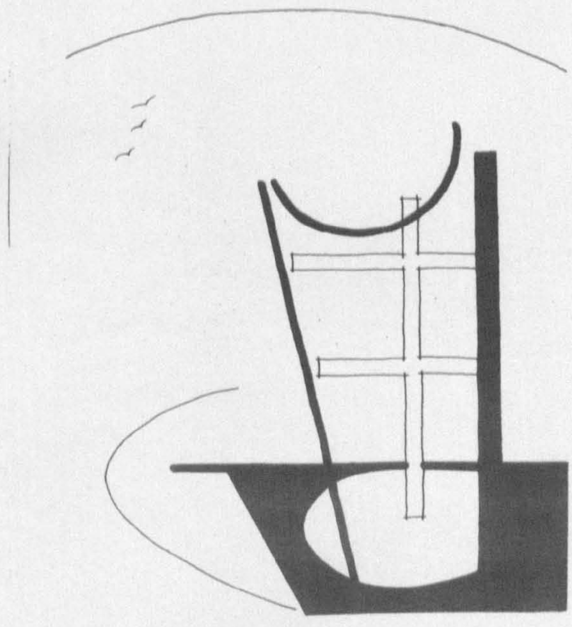
PROCURING THE URBAN HOUSE IN PARADISE

Charles Roy Smith



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To Joanne

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Note to the Reader

This thesis is accessible on three successive levels of depth. Firstly the Executive Summary provides a brief overview of the whole research project. At the start of each section throughout every chapter a short paragraph in bold text describes the purpose and outcome of that section, allowing the reader to understand each individual stage of the research and how it contributes to the final outcomes. Collectively these passages constitute the second level of accessibility. Thirdly the reader may choose to read the full document.

There are three volumes in the overall submission. The first contains the main thesis, from Introduction through to Conclusions, and constitutes the full write-up of the research project. Volume Two contains the drawn studies, architectural designs for urban housing projects, which were an integral part of the research methodology, and the write-up of those studies. The third volume contains ancillary and critical annexe information, such as background data and the detailed analysis that substantiates the research; the Annexes elaborate upon and justify issues raised in the first volume, but that are beyond its scope. It is intended that the three volumes can be read simultaneously.

... long is the way
And hard, that out of Hell leads up to Light;

Milton, *Paradise Lost*

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Abstract

The ambition of the thesis was to consider the performance of urban dwellings, and more specifically to develop a series of benchmarked criteria that holistically define the performance of an urban dwelling throughout its lifecycle, then to create an assessment tool that extends the scope of existing environmental evaluation models. The benchmarks for each of the criteria define the quantitative and qualitative performance values of firstly, a dwelling built to current regulation standards, secondly a European comparison, and thirdly one of the drawn studies undertaken as part of the research methodology; finally the performance of the 'urban house in paradise' is proposed, based upon advances to the above. These benchmarks provide a generic framework that describes the integrated performance of a dwelling.

The tool advances existing assessment models by responding to their identified shortcomings, which includes taking account of the interrelation between criteria and evolves significance weightings in terms of the relative priority of the criteria to each other. By attempting to resolve the linkages between the criteria, the tool as developed will model how these interrelated benchmarks effect each other within a given project, so that a holistic set of values, the ideal balance of priorities, can be developed. This will enable a designer to determine the best overall balance of a dwelling's performance, taking account of the identified relative significance of each of the criteria, to bring the sustainability of a project as close as possible to the ideal of the 'urban house in paradise.' Such a development provides an advance upon existing techniques in defining and assessing the ecological performance of a dwelling.

The contributions to knowledge made by this thesis are primarily in increasing the depth and scope of assessing the performance, and in particular the environmental performance, of dwellings. The field of criteria in existing environmental assessment methods is extended to include not only a broader, and therefore more holistic range than any other environmental assessment model, but also those relevant to socio-economic areas of sustainability. Prioritisation and interrelation between the individual criteria was developed in the assessment tool's methodology; interrelation is crucial, as sustainability demands a holistic view. Assessment and prioritisation methods are based on the philosophy of Deep Ecology, and not an anthropocentric orientation, therefore potentially creating a radical reappraisal of the criteria considered important in other assessment models. The prioritisation extends between fields, in search of most significant criteria within a holistic view and has identified, within the boundaries of what is technically feasible, the criteria that can contribute most to achieving more ecologically sustainable dwelling in a Deep Ecological sense.

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Tables

Nomenclature

$ac.h^{-1}$	Air changes per hour
$dw.ha^{-1}$	Dwellings per hectare
$g.kWh^{-1}$	Grammes per kilowatt hour
J	Joule (Unit of energy)
K	Kelvin (Unit of temperature, equal in magnitude to a °C)
$kg.m^{-2}$	Kilogrammes per unit area (Unit of mass per unit area)
$kg.m^{-2}.a^{-1}$	Kilogrammes per unit area per annum
$kgCO_2.a^{-1}$	Kilogrammes of carbon dioxide per annum
$kgCO_2.m^{-2}$	Kilogrammes of carbon dioxide per unit area
$kgCO_2.m^{-2}.a^{-1}$	Kilogrammes of carbon dioxide per unit area per annum
$kgC.kWh^{-1}$	Kilogrammes of carbon per kilowatt hour
kWh	Kilowatt hour (Unit of energy consumption, 3.6×10^6 J)
$kWh.m^{-2}$	Kilowatt hours per unit area
$kWh.m^{-2}.a^{-1}$	Kilowatt hours per unit area per annum
$l.m^{-2}$	litres per unit area
$l.p^{-1}.d^{-1}$	litres per person per day
$mg.kWh^{-1}$	Milligrammes per kilowatt hour
$m^2.p^{-1}$	Unit area per person
$m^3.p^{-1}$	Unit volume per person
Pa	Pascal (Unit of pressure, 1 Newton per unit area)
$p.ha^{-1}$	People per hectare
$£.m^{-2}$	Cost (pound Stirling) per unit area
$£.m^{-3}$	Cost (pound Stirling) per unit volume
W	Watt (Unit of power, or rate of energy consumption, $1 J.s^{-1}$)
$W.m^{-2}.K^{-1}$	Watts per unit area per degree Kelvin

Executive Summary

1.0 Introduction

The thesis opens by introducing the elements urban, dwelling and paradise, contextualising the research and establishing its significance. The urban environment has, in the recent past, become an increasingly relevant context in which to consider the dwelling as an integral part of sustainable development. The dwelling is a building type of contemporary relevance through both its universality and predicted growth; although individually small in scale, the contribution of the domestic sector upon the environment is significant. The dwelling has always been a decisive part of urban structure, enriched by the complexity of its functions; contemporarily there is an increasing drive toward a re-inhabitation of the urban dwelling. Paradise is conceived as a secular notion of an ideal, harmonious balance between the dwelling and the sustainability of the natural environment. The 'urban house in paradise' is proposed as a generic concept standing at the limits of feasibility; a departure point or principle that can be particularised, informing, rather than inhibiting, the creative design process. It is proposed as a way in which to conceptualise a new paradigm of dwelling design radically more sustainable than those currently built.

2.0 Methodology

Three stages to the research can be identified. Firstly the thesis determined the criteria that define, in terms of its sustainable performance, the generic 'urban house in paradise' and then attributed values to those criteria as benchmarks, attempting to innovate upon best practice in a northern European context. Secondly an assessment methodology was devised, through which urban dwellings can be assessed against the benchmarks of the 'urban house in paradise', aiming to identify the most sustainable balance of priorities. The benchmarks provide an objective way in which to define the performance of a dwelling. The assessment tool becomes the means by which a dwelling can be measured against the benchmarks of the 'urban house in paradise' at the design stage, and its performance refined. Finally the benchmarks and assessment tool were validated.

3.0 Scope

In terms of building type, the research focuses exclusively upon the dwelling, and in terms of geographical scope, is concentrated upon a northern European context. It aims to radically improve the sustainability of the dwelling, however is only part of a broader picture. The dwelling is a platform for a lifestyle, and other impacts of that wider picture will also have to be minimised if significant reductions in overall ecological impacts are to be achieved. Some criteria, such as density and functional diversity, will have an impact on lifestyle issues such as reducing transport; therefore the research can be considered to form part of an integrated approach to reducing overall ecological impacts.

4.0 Literature Review

An evaluation of current environmental assessment methods was undertaken to identify any shortcomings that the criteria and tool for measuring the 'urban house in paradise' could attempt to overcome, to advance knowledge in this field. Such areas included longevity of the dwelling and lifecycle appraisal, identifying interrelationships linking criteria, to reflect the holism that is a fundamental principle of sustainability, anthropocentrism and hierarchy between criteria.

5.0 Criteria

The criteria that define the 'urban house in paradise' attempt to encompass all quantifiable aspects of a dwelling throughout its lifecycle; a number of sources were used in determining the criteria to ensure that they are holistic. They are intended to be able to run parallel with the creative design process. Whilst they may inform that process, it is not envisaged that they will impinge or have a detrimental impact upon it; they are generic, and the 'urban house in paradise' could be realised in many different forms. The drawn studies are used in part to ensure that the research is not abstract to the design process.

6.0 Benchmarking

As a methodology for driving continuous improvement benchmarking has been used in other industries within the West for twenty years; the aim is to perpetually improve performance against best practice. Recently benchmarking has begun to be used within the construction industry, further establishing the relevance of the research. A commonality between the benchmarks proposed by others is that they are abstract percentages, and not quantitative, dimensional values. Therefore, quantitative benchmarks were established for each of the criteria; these constitute a way in which to define the performance quality of the 'urban house in paradise'. The values are informed by principles of sustainability such as Factor Four, of reducing resource consumption to one quarter of its current level. It is considered that such reductions should be over and above the predicted increase in dwelling numbers. Two case studies were made of dwellings that are representative of best practice on a

European level to demonstrate that the theoretical benchmarks proposed can, at least in part, be achieved in reality.

7.0 Prioritising

The lack of significance ratings between criteria is identified as a shortcoming in existing environmental assessment; therefore a hierarchy is established for the criteria that define the 'urban house in paradise'. This is based upon the relative significance of each in terms of improving the ecological sustainability of the dwelling using a Deep Ecological approach, as opposed to anthropocentric, as the philosophical underpinning for the methodology. In order to retain a manageable scope to the prioritising, the methodology was restricted to identifying the reduction in direct, measurable impacts against four types of ecological degradation, which collectively constitute a general view of environmental sustainability. These are global warming, pollution, natural resource depletion and ozone depletion. The reduction in impacts against each of those parameters that is achieved by moving from the benchmark of the typical dwelling to that of the 'urban house in paradise', in a Deep Ecological sense, was calculated for each of the criteria. These were converted into normalised ratios and summed to provide an overall weighting for each of the criteria.

8.0 Interrelationships

Holism and interconnection are fundamental principles in sustainability, and yet are absent in existing environmental assessment. The matrix of criteria attempts to codify the interrelated links between each other, so that a holistic representation of the performance of the dwelling is made. Creating these links is critical so that the assessment tool can identify the best overall balance of performance between the criteria. Potential links between the criteria were identified in three ways: the literature review of existing environmental assessment methods, dimensional analysis, and an evaluation of the stocks and flows diagram used to identify criteria. The links identified were used as the structure through which to evolve the assessment methodology. The next step was to determine the nature of the relationship that constituted each link. This would enable the assessment tool to account for the magnitude of the effect that altering one criterion would have upon the other. At this stage the scope of the research began to focus upon the eleven most significant criteria identified by the prioritising: energy consumption during inhabitation, energy generation during inhabitation, ventilation and air tightness, embodied energy, CO_2 emissions during inhabitation, design life span, pollution emissions during inhabitation, thermal performance, embodied CO_2 emissions, other greenhouse gas emissions and water consumption.

9.0 Assessment Tool

The assessment tool enables a dwelling to be benchmarked against the criteria of the 'urban house in paradise'; and is responsive to altering the performance to determine the most ecologically sustainable solution. Existing environmental assessment methods were reconsidered in terms of approaches to designing the assessment tool. The SAP assessment was used as the basis from which to develop the tool; providing a measurement of energy consumption it could be broken apart and expanded upon to assess the other benchmarks. Applied methodology, such as U-value calculations, was incorporated and new assessment algorithms developed, such as the pollutant emissions. Initially the tool was created as a worksheet, creating a step by step method for evaluating the performance of a dwelling against the benchmarks. Numbering each step enabled values and outcomes to be used elsewhere in the worksheet, creating interrelated links between criteria.

The performance of a dwelling being assessed against the benchmarks is presented in two formats. Firstly a profile of values for each of the eleven most significant criteria's benchmark is given. Then an overall score, using the weightings previously determined to account for the relative significance of the criteria, is then derived; varying the values entered to maximise this score will produce the most ecologically sustainable balance of performance between the criteria. With all of the algorithms determined in the format of a worksheet, they could be used to construct a computer spreadsheet version of the assessment. This reduces the time taken to assess a dwelling, improves its accuracy, automates the interrelated links between criteria, and facilitates graphical representation of the outcomes. Default values are used to further increase the speed of an assessment.

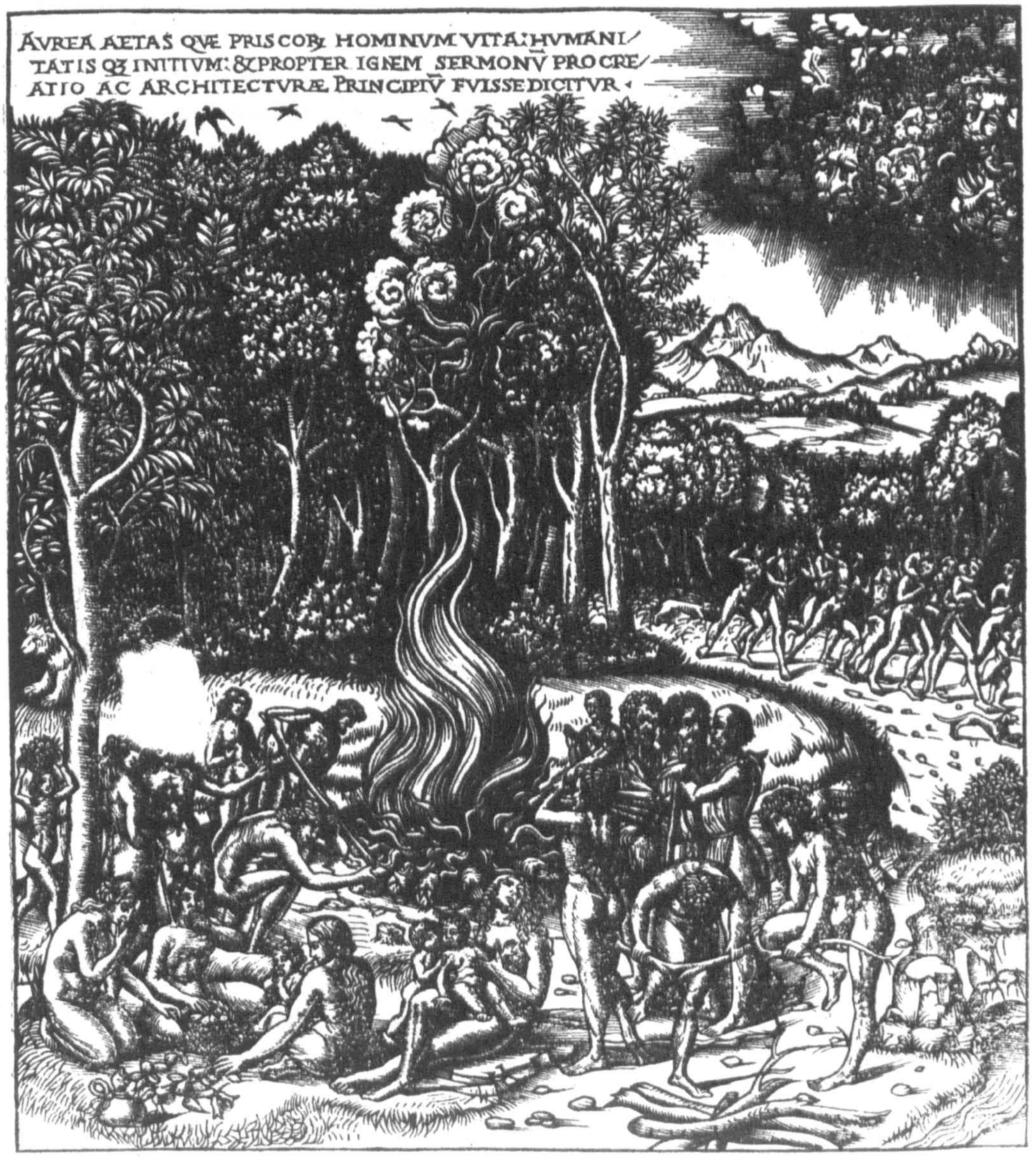
10.0 Validation

Derived from a multitude of sources, both primary and secondary, the benchmarks are validated within the final drawn studies to ensure they are achievable, and not mutually exclusive. The validation of the tool was achieved firstly by assessing a three bedroom semi-detached dwelling to determine how closely it predicts the values derived through literature review, secondly assessing the final drawn studies, and thirdly through specialist interview. Validating from three independent directions increased the confidence in its robustness. The validation using an assessment of a typical three bedroom semi-detached dwelling to determine the consistency between the predicted benchmarks and the values derived from the literature review, on a comparable basis, produced values within 5 percent of each other. Although not all of the benchmarks were achieved in the drawn studies, it was not considered that the values should be revised for this reason. However, thermal mass was proposed as an additional criterion, which would have a consequential impact upon the embodied energy and CO_2 benchmarks. The validation by specialist interviews sought the opinions of an architect and building services engineer on the tool, once they had conducted an assessment using it. Both identify the relevance of the tool, and therefore of the research. The assessment of embodied energy and energy consumption by appliances was identified as of particular significance. The weakest element was the time taken to undertake an assessment; this could be resolved by improving the interface and greater use of defaults.

11.0 Conclusion

If a wide scale adoption of the benchmarks of the 'urban house in paradise' were initiated, significant reductions in environmental impact of the domestic sector could be made. The 'urban house in paradise' represents an ideal, a dwelling radically more sustainable in a deep ecological sense than those produced today. However, this is not to say that the benchmarks proposed cannot be improved upon; the notion of continuous improvement is central to the philosophy of benchmarking. Therefore, the 'urban house in paradise' is something of a fluid concept, one that can continually be improved and innovated upon; its fluidity epitomises the appropriateness of the generic framework of benchmarks to the pluralistic nature of the creative design process. The benchmarks presented here represent the 'urban house in paradise' at this point in time, potentially on the cusp of a paradigmatic shift, as the sustainability of dwellings becomes an issue of paramount significance.

Chapter 1



Introduction

1.0 Introduction

Each of the elements of the term the 'urban house in paradise' are defined, and their scope and relevance established. The scope, aims and methodology of the research and its subsequent validation are then outlined to give an overview of the thesis.

1.1 Urban

The urban environment has, in the recent past, become an increasingly relevant context in which to consider the dwelling. A multitude of initiatives are indicative of the renaissance envisaged for towns and cities in the United Kingdom, to which dwelling constitutes an integral part of their sustainable development.

In 1994 the Dutch architect Rem Koolhaas wrote, "... the urban is about to become a major vector of the imagination."[1] During the recent past, urbanism and dwelling within urban areas has become a direction of thought with increasing magnitude in the United Kingdom. The current agenda of this urban renaissance is a response to a continual process of urbanisation, and a belief that the regeneration of cities can deliver increased sustainability in ecological, social and economic terms. This response is evident in many ways, including the Government's target that 60 percent of new housing be built on previously used land, with a significant proportion in urban areas, the Urban Task Force's report,[2] and the recent Urban White Paper which seeks to, "... make sustainable urban living practical, affordable and attractive to enable us to reduce the emissions, waste products and other local and global environmental impacts."[3]

However the growth in urbanisation is by no means limited to the United Kingdom, it is a worldwide trend. In July 2000 the Berlin Declaration on the Urban Future recognised that, "For the first time in human history, a majority of the world's six billion people will live in

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[1] Koolhaas, Rem and Bruce Mau. *S, M, L, XL*, Rotterdam: 010 Publishers, 1995, p. 969.
[2] Urban Task Force. *Towards an Urban Renaissance – Final Report of the Urban Task Force*, London: E & F N Spon, 1999.
[3] Department of the Environment, Transport and the Regions. *Our Towns and Cities: The Future – Delivering an Urban Renaissance*, London: HMSO, November 2000, p. 29.

cities."[4] More locally, it is estimated that, in the European Union, around eighty percent of the population lives within cities, towns and urban areas;[5] within the United Kingdom 9 percent live within an urban core.[6] In the essay *The Generic City*,[7] Koolhaas proposes that the continuing trend towards urbanity is a part of the growth of an increasingly generic urban culture, a trend towards the environment of the city irrespective of location or identity. These factual and philosophical references are indicative of the established opinion that the urban environment is, and will increasingly continue to be, a critically relevant context in which to consider the nature of the dwelling.

The term urban is derived from the Latin *urbs*, meaning 'city.' The word *urbs* is most probably of Etruscan origin, and it indicates the way in which the city was created and defined physically, ritually and legally.[8] The most important part of the founding ceremony of any town was the cutting of the *sulcus primigenius*, the initial furrow. This ritual which defined the periphery of any town that aspired to the title of 'urbs,' the sacred line of the wall and the divide between the urban and the rural, is said to have been imported from Etruria, as the Romans inherited most of their 'scriptures' from the Etruscans, which were written at an early stage of Latin literacy.[9] Therefore, in the origin of the urban condition, the distinction between urban and rural became a specific and sacred definition.[10] The term urban is used in reference to the inner and outer core areas of cities and towns. It is distinct from, and does not encompass, suburban areas.

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[4] Berlin Declaration on the Urban Future website, 21 August 2000: www.urban21.de/english/03-homepage/declaration.htm

[5] European Commission website, 26 March 1999:
www.europa.eu.int/comm/dg11/urban/home_en.htm

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

[7] Koolhaas, Rem and Bruce Mau. Op. Cit.

[8] The Etruscan derived *urbs* replaced the older Indo-European word, *tota* for city. Rykwert, Joseph. *The Idea of a Town*, Cambridge, Massachusetts: The MIT Press, 1988.

[9] The founder of the town, having gathered his followers at an agreed point, would set his plough so that all of the earth would fall inside the furrow, toward the town. With his head covered, he ploughed to define the site of the city. When he arrived at any points on the boundary that were to become gates, he took the plough from the ground and carried it across the width of the gate; it is this carrying (*portare*) that is attributed to the root of *porta*, a gate.

[10] The origins of urban culture preceded the genesis of the term *urban*. Herodotus's account of the rise of Deioces to power over the Medes, written around the fifth century BC, gives a rational account of the transition from village culture to urban culture that is free of the religious ideas that affect the accounts of late Stone and Early Bronze Ages. In a position of empowerment, Deioces directed the Medes, who were previously settled in dispersed villages, to build one city. Then, within the confines of that city, Deioces built fortifications of his own, around his palace; "... in lessening the physical distance by concentrating population in the city, Deioces took care to increase the psychological distance by isolating himself and by making access to his person formidable. This combination of concentration and mixture, with isolation and differentiation, is one of the characteristic marks of the

1.2 House

The dwelling is a building type of contemporary relevance. Although individually small in scale, the contribution of the domestic sector upon the environment is significant; with a predicted increase of 19 percent of the housing stock over 25 years this significance will increase. Furthermore, the dwelling has universality; it is a building type pertinent to all.

The focus of the research upon the house, or dwelling, as a building type also has contemporary and critical relevance. Despite being individually small in scale compared to other building types, in the United Kingdom the domestic sector as a whole is the second largest consumer of fossil fuels, on the basis of delivered energy, and the second largest cause of carbon dioxide (CO_2) emissions, by a slightly wider margin,[11] therefore the collective ecological impact is highly significant. Furthermore, the Department of Environment, Transport and the Regions has identified that the demand for new dwellings will increase; between 1996 and 2021 3.8 million new dwellings will be required in England,[12] a figure which represents an increase of nearly 19 percent of the existing number of households.

The level of CO_2 emissions from the domestic sector is at present approximately 157 million tonnes; the Government's target by 2010 is to reduce this to 134 million tonnes.[13] Significant improvements in the performance of new dwellings, in terms of their energy consumption and emissions, could impact upon the large rise in the housing stock, and contribute to achieving the Government's proposed target of reducing CO_2 emissions to 20 percent of their 1990 level by 2010.[14]

The dwelling is also particularly relevant as a building type through its universality. It is a

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new urban culture." Mumford, Lewis. *The City in History*, London: Penguin Books, 1991, p. 61.

[11] Department of the Environment. *Climate Change: Our National Programme for CO_2 Emissions*, London: Department of the Environment, 1992; and Department of the Environment. *The UK Environment*, London: HMSO, 1992.

[12] Department of the Environment, Transport and the Regions website, 2 July 1999: www.housing.detr.gov.uk/information/keyfigures/index.htm

[13] Department of the Environment, Transport and the Regions. *A Better Quality of Life – A Strategy for Sustainable Development for the United Kingdom*, London: HMSO, May 1999.

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

type relevant to all cultures and all people, as everyone needs somewhere in which to live. Furthermore, the dwelling can have more relevance and impact on personal values and association through the intimacy of its function, as opposed to other types. In addition to being an abode to all, the dwelling is also increasingly becoming a place within which to work. The rise in popularity of apartment dwelling in cities, encouraged through the Government's envisaged urban renaissance, is an indicator of a new paradigm in the nature of dwelling, at least in the United Kingdom.

The notion of the term *house* in the 'urban house in paradise' is intended to be broader than the two or three storey single-family dwelling, which one might initially preconceive it as. In German the word *haus* means something much broader than the English *house*; the latter does not typically extend its frame of reference to include the full range of dwelling types, and in particular urban dwelling types, such as flats and maisonettes. However, *haus* translates as both *house* and *building*,[15] and therefore encompasses all building types in which dwelling takes place. The *house* of the 'urban house in paradise' is therefore intended, in the sense of the German philosopher Martin Heidegger (1889-1976), to mean a place in which to dwell. Heidegger, in the essay 'Building, Dwelling, Thinking' wrote about the relationship between the process of building, for which the High German word is *buan*, meaning to dwell, and dwelling. On the nature of dwelling, he wrote, "The fundamental character of dwelling is ... sparing and preserving"[16], and continued:

> "Mortals dwell in that they save the earth ... To save the earth is more than to exploit it or even wear it out. Saving the earth does not master the earth and does not subjugate it, which is merely one step from spoliation."[17]

The notion of the relationship between the dwelling and the spoliation of the natural environment is a principal theme that will develop through this thesis.

1.3 The Urban Dwelling

Vitruvius' description of the origin of dwelling is also one of the origin of architecture.

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[15] Springer, Dr Otto (ed). *Langenscheidt's Encyclopaedic Dictionary of the English and German Languages – Part II*, Langenscheidt, 1997.
[16] Heidegger, Martin. 'Building, Dwelling, Thinking'; in Leach, Neil (ed). *Rethinking Architecture - A Reader in Cultural Theory*, Routledge, 1997, p. 102.
[17] Ibid., p. 103.

The concept of dwelling is perceived as an integral part of the public realm of the city, creating connections between urban and dwelling. The dwelling has always been a decisive part of urban structure; enriched by the complexity of its functions. In contemporary terms, there is an increasing drive toward a re-inhabitation of the urban dwelling.

In *The Ten Books of Architecture* Vitruvius describes the origin of the dwelling house. His account is more than one of the creation of a detached and autonomous object, in a sense it is a description of the origin of architecture; an architecture unconcerned about its exteriority but with attention directed toward the process and rituals of construction and eventual inhabitation of the dwelling. Vitruvius' treatise is a reflection on the origin of dwelling as a concept or phenomenon, rather than the first dwelling as an object or artefact in itself.

Dwelling, for Vitruvius, was a more profound and involved concept than just the creation of shelter; it was an integral part of the public realm of the city. The condition of living as an engagement with the urban realm was an essential attribute of dwelling among the Romans, for whom Vitruvius writes (more specifically, the emperor Augustus). The section dedicated to the origin of the dwelling follows Book One, which is devoted to the site and layout of the city:

> "Vitruvius wrote about the dwelling only after he had commented on the siting and layout of the city in Book One. The city and the house, or the place of gathering and the dwelling for the individual human being, are thus engaged in an intense relationship that is fundamental to this discourse on architecture."[18]

As Vitruvius has identified, in the creation of an urban environment dwelling has always been a decisive part of its structure.[19] In *The Republic*, Cicero recognises,

> "... a sort of innate desire on the part of human beings to form communities. So these groups ... first founded a settlement in a fixed place for the purpose of building

[18] Dripps, R. D. *The First House - Myth, Paradigm, and the Task of Architecture*, Cambridge, Massachusetts: The MIT Press, 1997, p. 4.

[19] The urban dwelling, conceived of as a piece of architectural design like the rural villa, began, for the first time since the end of the Roman era, to reappear in sixteenth century Italy, through an impetus generated by increased affluence and the aspirations of the Renaissance. This re-emergence is marked in time by the Italian architect Sebastiano Serlio's (1475-1554) *Book VI* on domestic architecture, drafted between 1551 and 1553 but not published until 1967, which is acknowledged as the first treatise on the typology of domestic architecture in the Western World, and includes the

houses ... they called such a collection of dwellings a town or, when it had been laid out with shrines and public spaces, a city."[20]

The significance of the relationship between the urban environment and the dwelling, and therefore of the urban dwelling as a type, is also reflected in Alberti's dictum that the design of a city and a dwelling should be considered as one,[21] "... the city is like a large house, and the house in turn is like a small city."[22] Hans Kollhoff identified every urban settlement as being liveable and ecological, provided that dwelling is a decisive part of its structure; in return, dwelling as a part of urban building becomes enriched by an urban complexity of functions to become 'habitation' in its broadest, most diverse, sense.[23]

In contemporary terms, following a century of movement towards rurality through suburbanisation, there is an increasing drive towards a re-inhabitation of the urban dwelling. Across Europe there already exists an advanced culture of urban living, and within the United Kingdom, through an urban renaissance to be generated by the need for 3.8 million new homes within the next twenty years, the majority of which are to be on urban sites, the tradition of urban dwelling will become critically polemical.

1.4 Paradise

Paradise, within the scope of this thesis, is conceived as a secular notion of an ideal, harmonious balance between the dwelling and the sustainability of the natural environment, in a Deep Ecological sense. Current attitudes to sustainability are frequently anthropocentric, based solely upon human interests; the focus upon Deep Ecology seeks to overcome this, to achieve an ideal condition of nature in harmony with the manmade environment.

The notion of paradise as an ideal condition is a tradition. It was used in the Septuagint, the Greek version of the Old Testament, as a term for the garden of Eden; throughout history,

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specific distinction between the country and urban dwelling. Rosenfeld, Myra Nan. *Serlio on Domestic Architecture*, New York: Dover Publications Inc., 1996.

[20] Cicero, (translated by Niall Rudd). *The Republic*, Oxford: Oxford University Press, 1998, p. 19.

[21] Boyer, M. Christine. *The City of the Collective Memory – Its Historical Imagery and Architectural Entertainments*, Cambridge Massachusetts: The MIT Press, 1998.

[22] Alberti, L. B. *De Architettura IX*, in Borsi, Franco. *Leon Battista Alberti – Complete Edition*, Oxford: Phaidon, 1977, p. 326.

the garden of Eden has been used as an allegory for an ideal realm or perfect state, albeit an unattainable realm for the mortal dweller on earth. Paradise is a universal concept, trans-cultural and trans-religious, and therefore becomes a suitable metaphor of an ideal generic type; the history of Eden is a shift from the mythic to metaphor. However, with a multitude of associations and implications, the term must be used following a definition of the extent of its reference.

It could be argued that as the house is a man-made artefact, the 'urban house in Utopia' would be a more accurate use of nomenclature, in terms of the historical antecedence of paradise. Since its origin in the 1516 depiction by Sir Thomas More, of an imaginary island with a perfect social, legal and political system, with its roots in Plato's classical representation of the perfect republic, Utopia has symbolised a man-made construct; whilst in Judaistic religion paradise is a God-given, divine state. More's ideal island inspired a series of Utopias, including Andrea's *Christianopolis* of 1619, Campanella's *City of the Sun* of 1623 and Gott's *Nova Solyma* of 1648; all of which, like More, describe the construction of their buildings and cities, their man-made environment.[24] Subsequently, however, the concept of Utopia has become predominantly associated with political and social idealism, in particular through the evolution of communism. This trend began in the latter half of the 18th century, epitomised by books such as Harrington's *Oceana* and Winstanley's *Laws of Freedom* which are more in the nature of political manifestos.[25] Whilst social qualities are an intrinsic part of sustainability, the overbearing relation of the ideal social programme to the concept of Utopia renders it an unsuitable metaphor for the state in which the ideal dwelling will be located. Furthermore, as "... the germ of Utopian fiction is probably to be found in ancient descriptions of paradise"[26], a reference to Utopia would have implicit connotations to paradise anyway.

The theocratic interpretation of paradise as a God-given place is equally unsuitable. Therefore, in the context of this thesis, the term 'paradise' is reclaimed for secular use, as

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[23] Kollhoff, Hans. 'Urban Building Versus Housing,' *Lotus*, Number 66, p. 101.
[24] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames and Hudson Limited, 2000.
[25] Ibid.
[26] "In The Epic of Gilgamesh, Utnapishtim, the Sumerian equivalent of Noah, is discovered 'taking his ease on his back' in a place where, '... the croak of the raven was not heard, the bird of death did not utter the cry of death, the lion did not devour, the wolf did not tear the lamb, the dove did not mourn, there was no widow, no sickness, no old age, no lamentation.' " Quoted in Turner, Paul's introduction to More, Thomas. *Utopia*, London: Penguin Books, 1965, p. 16.

defining a steady state of harmony between landscape, nature and sustainability. The interpretation of paradise in eastern religion is that of a perfect natural environment occurring without the intervention of god. In western religion, there was a deep-seated belief by man that he could change nature in search of the paradisical. Henri Frankfort claims that Judaism sacrificed,

> ... the greatest good ancient Near East religion could bestow – the harmonious integration of man's life with the life of nature – Man remained outside nature, exploiting it for a livelihood ...[27]

As an ideal, harmonious and sustainable relationship with the natural environment, paradise is also of critical relevance. Current pressures being placed on the resources and ecosystems of the planet cannot be maintained; unsustainable practice at present rife within the house building industry must be superseded by ones that are more viable in a long-term global perspective. The consequences of these impacts, such as signs of global warming to take just one of the plethora of impacts humans have upon the environment, are already evident:

> "In the past two decades, average annual temperatures have climbed as much as 4 °C in Alaska, Siberia and parts of Canada. Sea ice is 40 percent thinner and covers 6 percent less area than in 1980."[28]

However, the serious impact of global warming is not limited to high northern latitudes. The Arctic plays a significant role in the global climate system by dissipating heat from the tropics; should the poles continue to warm faster than the tropics, the system may be slowed down, altering prevailing winds, ocean currents and rainfall patterns.[29] This would hinder or arrest the cyclic ocean current which brings warm water from the Gulf Stream, the effect of which would be to lower temperatures in Europe and North America; an ironic consequence of global warming. Furthermore, global warming is but one of a myriad of destructive impacts that human actions have upon the natural environment; others include ozone layer depletion, both renewable and non-renewable resource consumption, habitat

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[27] Frankfort, Henri. *Kingship and the Gods*, Chicago University Press, 1948, p. 342; in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995.

[28] Linden, Eugene. 'The Big Meltdown', *Time*, Volume 156 Number 10, 4 September 2000, p. 66.

[29] Melting ice in the Arctic caused by a temperature rise of a few degrees would create a layer of freshwater floating on top of the saltwater in the north Atlantic, preventing cooler water sinking, this would hinder or arrest the cyclic ocean current which brings warm water from the Gulf Stream.

destruction, water and air pollution, eutrophication and deforestation.[30]

With roots in the ecological revolution of the 1960s, typically dated by the publication of Rachel Carson's *Silent Spring* in 1962,[31] the Deep Ecology movement was defined by the Norwegian philosopher Arne Ness in 1972, who has continued to develop and refine its position to the present day. Largely unknown outside Scandinavia, it was not until the 1980s that Deep Ecology began to receive wider attention from both philosophers and environmentalists.[32]

The philosophy underpinning Deep Ecology made itself distinct from other contemporary ecological thought through its non-anthropocentric basis. It conceives the natural environment as a holistic interrelated system, in which the human race is at most an equal, and never superior, to other forms of life; all ecosystems, whether humans are affected by them or not, are of equal value. Rather than perceiving nature as a resource for human exploitation, Deep Ecology argues that the value of nature is independent of its utility. There are a large number of interpretations and definitions of sustainability; but the most commonly accepted, general one has a clear anthropocentric bias. The Brundtland definition of sustainable development is that which, "... meets the needs of the present without compromising the ability of those in the future to meet their own needs."[33]

Deep Ecology is a philosophy, "whose values reflect an awareness of the integrity of the whole of nature."[34] A Deep Ecological, or 'eco-centric', view of sustainability, as opposed to anthropocentric, is one in which the well-being of all natural systems on the earth are considered equally, as opposed to just the well-being of ones with a direct effect upon the human race. Integral with the Deep versus shallow philosophy of ecology is the question of

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[30] In terms of proposing more sustainable patterns of habitation, in which man is more harmonious with nature, it could be possible to take the natural environment itself as a precedent: "Imagine an industrial system that has no provisions for landfills, or smokestacks. If a company knew that nothing that came into its factory could be thrown away, and that everything it produced would eventually return, how would it design its components and products? The question is more than a theoretical construct, because the earth works under precisely these strictures." Hawken, Paul, Amory Lovins and L. Hunter Lovins. *Natural Capitalism – The Next Industrial Revolution*, London: Earthscan, 1999.
[31] Carson, Rachel. *Silent Spring*, Boston: Houghton Mifflin, 1962.
[32] Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala Publications Inc., 1995
[33] World Commission on Environment and Development. *Our Common Future (The Brundtland Report)*, Oxford: Oxford University Press, 1987, p. 43.
[34] Snyder, Gary. 'Culture or Crabbed,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala Publications Inc., 1995, p. 49.

the intrinsic value of all species for their own sake, and therefore: "... what, if any, ethical obligations humans [have] to the nature of other species."[35] This epitomises the issue of the wider obligations that humans have to the impacts made on all species and ecosystems, and not merely the ones whose degradation affects humans, which is implied by the Brundtland definition.

In the focus of its concern on the holistic ecology of the planet Deep Ecology does not necessarily exclude the urban environment. "It is right and proper that the movement should run from wildlife to urban health. But there can be no health for humans and cities that bypass the rest of nature."[36] There is, therefore, a relationship between the perception of the natural environment in a Deep Ecology sense, and the nature of 'paradise', as an ideal condition of nature in harmony with the manmade environment. Deep Ecology is also of relevance in the context of the aim of the thesis to create a holistic matrix that demonstrates the interconnection between the criteria within it. A principle of Deep Ecology is that is perceives the world as a network of phenomena that are fundamentally interconnected and interdependent.[37] The physicist Fritjof Capra stresses the shift from an anthropocentric perspective to an organic, ecologically interrelated, holistic systems view.[38]

Capra, writing of the ethics associated with the new ecological paradigm of Deep Ecology, states that, "... the most important task for a new school of ethics will be to develop a non-anthropocentric theory of value, ...".[39] In view of the emphasis placed on the balance between the natural environment and man, and the definition of paradise as an ideal condition of nature, the philosophy of Deep Ecology is of significant relevance to the thesis. As a theoretical notion of sustainability that encompasses a greater relationship between man and nature, Deep Ecology becomes a justifiable intellectual paradigm to inform it.

The thesis acknowledged that sustainability has three related spheres; whilst considering the dwelling in terms of them all, the research focused upon the ecological sustainability of the dwelling. Cole writes that, "Irrespective of the social and economic context, the health

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[35] Foreman, Dave. 'The New Conservation Movement,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala Publications Inc., 1995, p. 52.
[36] Ibid.
[37] Capra, Fritjof. 'Deep Ecology - A New Paradigm,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala Publications Inc., 1995.
[38] Sessions, George (ed). Op. Cit.
[39] Ibid., p. 20.

of the biosphere is the limiting factor for sustainability."[40] The Brundtland definition has a clear anthropocentric bias, which was considered inappropriate toward the focus upon ecological sustainability. Therefore Deep Ecology was used to inform the scope of the term sustainability within the thesis, toward reducing the impact of the dwelling in, for example, resource consumption and consequent emissions in the context of any natural system, as opposed to specifically those solely of human interest.

1.5 The 'urban house in paradise'

The 'urban house in paradise' is proposed as a generic concept, a departure point or principle that can be particularised through context and creative design. It is defined by its holistic performance, which is as close to ideal as technically achievable; therefore it stands at the limits of feasibility; a dwelling that is radically more sustainable than those currently built.

In the first chapter of *On Adam's House in Paradise*, Joseph Rykwert proposes the idea of Adam's house arising from the rituals and needs of dwelling in the Garden of Eden. The vision of Adam's house, the first house in paradise, as Rykwert states, "... seems to have haunted everyone involved in building (long before building was distinguished from architecture)."[41] For Rykwert, the house in paradise is a non-contextual concept, as opposed to an object; lost in the sense that it also is an unattainable ideal, as oppose to an artefact;[42] traditionally this is most frequently represented by the walled enclosure of the Garden of Eden.

Rykwert goes on to identify ways in which the notion of this house in paradise, the first house as a recollection of a *type*, has been invoked as a justification, a departure point, for architectural theory throughout history. It is a first principle that has had a long history, and is as old as architectural theory itself. He identifies how Marc-Antoine Laugier in his 1753 *Essai sur l'Architecture* describes the primitive hut as a source of the essential elements of

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[40] Cole, Raymond J. 'Building Environmental Assessment Methods: Clarifying Intentions', *Building Research and Information*, Volume 27 Issue 4/5, 199, p. 234.
[41] Rykwert, Joseph. *On Adam's House in Paradise - The Idea of the Primitive Hut in Architectural History*, Cambridge, Massachusetts: The MIT Press, 1981, p. 13.
[42] Ibid.
[43] Ibid.

architectural principles,[43] "... the architecture of man in an idyllic, unprejudiced and natural state."[44] Therefore the primitive hut, Rykwert's house in paradise, becomes a source of architectural principles.

In terms of a frame of reference, paradise is used on the provision that it defines the ideal of a man-made environment in harmony with nature in a Deep Ecological sense.[45] The combination of an ideal and its unattainable state, with which paradise is frequently associated through its depiction of being a walled garden, naturally creates a feeling of desirability. In the context of this research, the reference to paradise is also intended to convey this concept of desirability.

In a philosophical sense the 'urban house in paradise' is conceived as one ideal dwelling, standing at the limits of feasibility; one that is radically more sustainable, in a Deep Ecological sense, than those currently being built. It is proposed as a generic type, and therefore can adopt a myriad of incarnations; it is embodied as a holistic set of principles, to paraphrase Laugier, in the form of performance criteria. Benchmark values are developed for these criteria, the standards of which are as close as is technically feasible to an ideal; therefore the 'urban house in paradise' is measured against these values. A protocol, or tool, is developed to provide the methodology to undertake such as measurement.

1.6 Thesis

The thesis determined the criteria that define the generic 'urban house in paradise' in terms of its sustainable performance, then attributed values to those criteria as benchmarks quantifying that performance. An assessment methodology was then devised, through which urban dwellings can be assessed against the 'urban house in paradise'.

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[44] Pérez-Gomez, Alberto. *Architecture and the Crisis of Modern Science*, Cambridge Massachusetts: The MIT Press, 1996, p. 62.

[45] The influence of the man-made has always been an intrinsic part of paradise; for example, Eden was a garden which man was to tend. Also, Milton's heaven in *Paradise Lost* contains many architectural and urban elements: "The hasty multitude / Admiring enter'd, and the work some praise / And some the Architect: his hand was known / In Heav'n by many a Tow'red structure high, / Where Scepter'd Angels held their residence, ..." Milton, John. *Paradise Lost*, London: Penguin Books, 1989, p. 25.

The notion of the 'urban house in paradise', for the purposes of this thesis is, as for Rykwert, a dwelling as a generic type available to all. In this case it is the ideal sustainable urban dwelling, represented as a collective of the performance characteristics that define the design, procurement, construction, life-cycle and of the 'urban house in paradise'.

Therefore, the proposition for this thesis was to determine and value the criteria that define, in terms of its sustainable performance, the 'urban house in paradise' as a contemporary ideal; this definition took the form of a series of benchmarks, or standards against which those criteria can be assessed. Through the drawn studies the thesis determined if as an ideal type, the genesis from which all subsequent interpretations are made, the 'urban house in paradise' could be realised; in other words, to determine if it is a provable concept.

Once these values were generated, the thesis then proposed to develop a validated methodology of assessment for the benchmarks.[46] This would be a tool through which urban housing projects could be assessed to determine how closely they achieve the performance of the 'urban house in paradise'; the tool would become an indicator of the sustainability of the dwelling. This would be both an analytical and predictive tool that can be used by architects. The assessment of these intertwined criteria required the creation of a model capable of determining the consequential effects on the other criteria of altering one criterion toward or improving upon its benchmark value. Thereby one could identify if changing certain values would achieve a level of sustainability closer to that of the 'urban house in paradise', and thereby attain the best overall balance of priorities. For example, increasing the thermal performance of the fabric of the dwelling would reduce the energy consumed by that dwelling during its life span; however, if the increase in the level of embodied energy of the materials were above that of the additional energy saved, then this would not be a sustainable move toward the 'urban house in paradise.' Or, the additional material could increase the construction cost by more than is saved through the improved thermal performance, in which case an informed decision could be made to prioritise one benchmark value over another. The value of prioritisation in the design of a dwelling is that it offers direction to an evolving solution by providing a basis of comparison between alternative strategies.

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[46] The methodology, or tool, will be validated, in order to ensure its accuracy, through different means: analysis against the proposed final drawn studies that are an integral part of the research methodology, and through critiques with relevant specialists. This will ensure confidence in both the

The criteria, benchmarks and assessment tool provide a designer with the data and methodology to evaluate the ecological sustainability of a dwelling against standards that innovate upon best practice in a northern European context. The tool establishes how varying the benchmarks could improve the overall sustainability of the dwelling. Through creating both a hierarchy and interrelated links between the criteria the thesis provides an advance upon existing environmental assessment methods.

1.7 Aims

The generic benchmarks attempt to establish performance standards that innovate upon best practice in a northern European context. This genotype of the urban dwelling can then be particularised into a specific form. The benchmarks aim to inform, not inhibit, creative design; the drawn studies are used in part to ensure that the 'urban house in paradise' is not abstract to the design process. The thesis also aims to address economic and social, in addition to ecological, sustainability.

The thesis aimed to explore and define what the contemporary ideal performance standards for a generic urban dwelling, within a northern European context, would be in terms of both their subject and their numerical value. The contemporary notion of the 'urban house in paradise' is the manifestation of the ultimate limitations of these standards, or performance benchmarks. Benchmarking is, essentially, the establishment of key performance targets for the purposes of intra-industry comparisons of best practice. Taking ecological impact as an example, the 'urban house in paradise' would be an ideal located within the dynamic state of sustainability, a balance of contribution against consumption; indeed it could even be a net provider towards overall ecosystem balances. This generic ideal dwelling will be a genotype of the urban dwelling; a non-contextual ideal type which is beyond the influence of critical regionalism in its conception, the genesis of the urban house embodying its ultimate performance standards. It is from this ideal genotype that particularisation, its interpretation and ability to respond to contingent factors, can be made. This is when, continuing the example of ecological impact, the climate of a region and impact of a site will have an influence, as well as factors such as contextuality.

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performance benchmark levels of criteria proposed by the matrix, the interrelationship between those benchmarks, and the working process of the assessment tool itself.

The design process could be defined as a creative response to create a solution to an identified need. It is intended that the generic framework of benchmarks will not be inhibitive to this process, or restrictive to the creative architectural development of dwellings. Rather the framework is proposed as a tool to be used alongside the creative development of an idea; it provides the methodology of testing the performance of that design solution against given criteria.

"Architectural knowledge ... combines practicality and artifice; scientific and artistic ways of thinking."[47] The criteria, benchmarks and their assessment are intended to be a way in which to inform the scientific strand of architecture without inhibiting, and potentially informing, the artistic strand. They are not intended to dictate the creative process, proffering a monastic approach to design; rather, it is intended to harmonise with it, to run in parallel or intertwine, like a DNA strand, informing but not impacting upon its direction. Pluralism is inherent to design. The drawn studies which constitute a significant element of the research methodology, are used in part to ensure that the development of the criteria, benchmarks and assessment tool are not abstract to the process of design.

1.8 Scope of the Research

The criteria that define the 'urban house in paradise' attempt to encompass all quantifiable aspects of a dwelling throughout its lifecycle; indirect issues, arising from the inhabitants of the dwelling, but beyond its boundaries, are not included. However it is recognised that the dwelling is only part of a broader picture, the other impacts of which will also have to be minimised if significant reductions in overall ecological impacts are to be achieved.

The scope of the work, in terms of building type, focuses exclusively upon the dwelling. This type was selected because of its relevance and universality established above. The research attempts to holistically appraise the objective, measurable performance of the dwelling, but does not encompass architectural quality; however, the criteria to potentially do so are discussed.

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[47] Duffy, Dr Francis. 'Our Future: The Analysis is Done, Now is the Time for Action', in *RIBA Strategic Study – Volume Three*, London: RIBA Publications.

The research is intended to cover all direct, definable performance aspects of a dwelling throughout its life span. It proposes radical improvements to the sustainability of the dwelling; however, it is only part of a broader picture. The dwelling is a platform for a lifestyle, and other impacts of that wider picture will also have to be minimised if significant reductions in overall ecological impacts are to be achieved. For example, the benchmarked reduction in carbon dioxide emissions would equate to 4.7 tonnes per annum for a typical three bedroom semi-detached dwelling; as a car produces approximately 0.3 kilogrammes of carbon dioxide per mile,[48] if it travelled 16,000 miles per annum it would produce more emissions than the dwelling saves. These wider and indirect consequences arising from the household, such as car use, are not included within the research. Because of the complexity in quantifying such aspects due to, for example, the potentially unpredictable nature of human behaviour, they are considered beyond the scope of the thesis. It should be recognised that the dwelling can only have a limited impact in increasing a broader scope of sustainability. However some criteria, such as density and functional diversity, will have an impact in reducing transport need; therefore the research can form part of an integrated drive toward improving the sustainability of lifestyle, through means such as reducing transportation, reducing overall ecological impacts.

In terms of geographical scope, the research is focused upon a northern European context. This is primarily due to the climatic impact upon the performance of the dwelling, which will affect, for example, its energy consumption through space heating.

1.9 Intellectual Framework

Paradigms are a structure through which to interpret the evolution of science or, more generally, knowledge. The 'urban house in paradise' is proposed as a way in which to conceptualise a new paradigm in dwelling design.

The American scientist Thomas Kuhn (1922-1996) interpreted the history of science as a cyclic process: periods of so-called 'normal science' running between scientific revolutions. The periods of normal science are identified by what Kuhn referred to as a paradigm, or

[48] Personal communication from John Whitelegg, Professor of Environmental Studies, Liverpool John Moores University, 28 November 2000.

'common disciplinary matrix'; in other words, a consensus of view. Revolutions, or paradigmatic shifts, occurred when new theories, arising from experiment and observation, became incompatible with existing scientific theory, and so general theory shifted to adopt these new theories, and reject the old.[49] In *Cities in Civilisation*, Peter Hall draws a parallel between art and science through Kuhn's theory of paradigms, in that both develop as a series of creative leaps.[50] In its broadest sense, the word paradigm means an exemplar or pattern that can serve as a model for future work.[51]

In terms of Kuhn, the performance benchmarks to be proposed by the thesis will constitute a new disciplinary matrix in the field of urban housing theory; a new paradigm, "... implies a new definition of the field."[52] This new definition will be in terms of the holistic matrix of benchmarks that will define the performance of the generic 'urban house in paradise'. The paradigm shift that the benchmarks constitute represent the adoption of a new philosophy rather than a destructive overturning of the existing condition; a shift to abandon the traditional linearity of lifecycle in housing construction, into a loop where extraction, construction, inhabitation and deconstruction are considered as a continuous, integrated process. This cyclic view is essential to sustainability.

During a period of normal science, should it transpire that problems cannot be resolved through existing theory, then new ideas are generated, and it is these that constitute the

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[49] Kuhn, Thomas. *The Copernican Revolution*, Cambridge, Massachusetts: The Harvard University Press, 1957.
[50] Hall, Peter. *Cities in Civilisation*, Weidenfeld & Nicolson, 1998.
[51] In *The Structure of Scientific Revolutions*, the term becomes much more specific: "Kuhn compared the shift from one paradigm to another to a gestalt flip ... But for Kuhn the shift is more profound; he added that, 'the scientist does not preserve the gestalt subject's freedom to switch back and forth between ways of seeing.' " Weinberg, Steven. 'The Revolution That Didn't Happen,' *The New York Review*, 6 May 1999, p. 48. For Kuhn the theory of each successive paradigm, or period of normal science, was incommensurate with the previous ones. The theory and culture of one paradigm changes so significantly that after a scientific revolution it becomes virtually impossible to see things as they had been seen under the previous paradigm.

In his theories on the development of education, based on developmental cognitive science, Howard Gardener seeks to develop an approach to teaching that is more responsive to the way which children learn. "To many psychologists, the development of knowledge in children looks a lot like the development of knowledge in science. Children seem to construct successive theories of the world that are the product of both their earlier theories and new evidence." Gopnik, Alison. 'Small Wonders,' *The New York Review*, 8 October 1998, p. 34. In other words, children change an existing understanding of a concept on the basis of new information they receive, and that new understanding is more accurate than the previous. This demonstrates a remarkable similarity between the nature of Kuhn's paradigm and the nature of human learning, and therefore the core of being human.

basis of the next paradigm. In other words, should it emerge that the benchmark matrix cannot be achieved through traditional approaches to housing construction in the United Kingdom, to realise the standards set by the benchmark-driven paradigm the construction industry may have to undergo a 'revolution'. The Construction Taskforce report, the Millennium Communities competitions, along with the Latham report, have proposed ways in which such a 'revolution' could occur. This is not to say that, as Kuhn later envisaged, that there could be no crossover between the two sides of the revolution, but that new thinking, a new culture, is required to achieve the shift; perhaps the term evolutionary, rather than revolutionary, would be more appropriate.

The new paradigm of the generic 'urban house in paradise', as defined by the benchmark matrix, is a new way in which to view the nature of the dwelling, and from this new conceptualisation, a new reality can be physically constructed. The benchmarks provide a way in which to facilitate a paradigm shift. Whilst some of these standards may already exist individually in specific European counties, the thesis seeks to establish a range of performance benchmarks that, as a set, an interrelated matrix, are compatible, and can be cohesively integrated into a housing project to be relevant and innovative in cross northern European housing practice.

1.10 Methodology

Three stages to the research can be identified. Firstly the criteria and corresponding benchmarks values that define the holistic performance of the 'urban house in paradise' were determined, which are derived from a multitude of sources. Secondly an assessment methodology to measure those benchmarks, identifying the most sustainable balance of priorities, was devised. Finally the benchmarks and assessment were validated.

The research contains three specific stages. Firstly, to determine the criteria and benchmark values that, through literature review and the drawn studies, proposed by the thesis and conducted as an integral part of the research, are of critical importance to defining the holistic performance and sustainability of a dwelling project. Secondly, to

[52] Kuhn, Thomas. *The Structure of Scientific Revolutions (Third Edition)*, London: The University of Chicago Press, 1996, p. 19.

devise a protocol, or tool, that will determine the consequential effects of moving criteria towards the benchmark values upon each other, in order to determine the ideal overall balance of priorities for a project at the design stage. Thirdly, to validate and refine the tool through analysis of the drawn studies and through critiques by relevant specialists. This will create confidence in the accuracy of the model, and suggest potential revisions or refinements to be made in future development.

The parameters to which values will be attributed will be selected as the key, and critically important, criteria that define the concept of the sustainable 'urban house in paradise', which will be derived from a number of sources, encompassing both primary and secondary research. These sources will include, the drawn studies undertaken during the first period of the research,[53] the performance-based criteria of the Urban Housing Design and Procurement Database,[54] and extensive literature searches of both comparable models of environmental assessment and of European best practice in dwelling construction. They will, therefore, embody contemporary best practice in European housing, and the aspirational targets currently being developed through mechanisms such as the Construction Taskforce report and the Millennium Village competitions.[55]

The drawn studies are designs for a variety of urban housing projects in differing contexts, and constitute a significant part of the research methodology. Studies One to Five contribute to determining the criteria of the tool, and their respective benchmark values. Studies Six to Eight are used to validate both the proposed benchmark values, to ensure that they are achievable and not mutually exclusive, and also the tool itself, as it would be used in the design of a new dwelling. The tool is also validated through interviews with relevant specialists.

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[53] For example, the initial drawn studies generated rudimentary values in terms of space standards, energy performance, in terms of thermal efficiency and cost, construction cost and waste. These figures were then refined and developed through input from other sources, and via critical analysis of the studies toward improving these standards.

[54] The UHDPD is a set of 128 criteria derived, during the initial stages of this study, to assess urban housing projects on a European and worldwide scale. These criteria are both objective and subjective, and it is the objective that incorporates performance characteristics. A full list of the UHDPD criteria, including the subjective, which assess the architectural quality of a project, is contained in Annexe 4.0, volume 3.

[55] In addition, in the context of the Construction Taskforce's avocation of increased standardisation in the construction industry, the thesis will also consider the inherent benefits to these benchmark values of increased standardisation and industrialisation to the sustainable performance of an urban dwelling.

A performance evaluation must have base-line figures, the benchmarks, from which performance is assessed. A common base-line benchmark in existing models is the typical, or average, performance. The average value of criteria can prove difficult to determine, as mean values of performance are likely to improve or be re-defined; this is an aspect of assessment that the matrix of benchmarks will address. As a basis for evaluation, the Canadian Building Environmental Performance Assessment Criteria (BEPAC) uses the performance expected through 'best practice approaches'. As opposed to proposing mean performance benchmarks, the assessment tool will be based upon ideal aspirational standards of the 'urban house in paradise'.

The tool will provide, in effect, an overall sustainability indicator, "An indicator is a representation of linkages whereby multiple effects can be monitored by a fundamental indicator."[56] Existing models, such as *EcoHomes*,[57] can be taken as a start point, but built upon to include the wider scope of sustainability, as proposed by the thesis. Unlike the *EcoHomes* model, in which the criteria are all assessed independently, through the tool one will be able to determine the effect on the overall sustainability of the model through altering the values of the criteria, toward, over or below that of the benchmark. It is also crucial that it is sufficiently dynamic and flexible, to accommodate future change over time as both the field of assessment and the baseline standard of best practice continue to evolve.

Methodologies from other disciplines present a rational basis for deriving prioritisation between criteria, identified as lacking from existing assessment tools.[58] The Analytic Hierarchy Process[59] (AHP) is capable of combining both qualitative and quantitative, in AHP terms *tangible* and *intangible*, attributes into a hierarchy of components, determining the priorities for all elements within the hierarchy. Within the process the user, or designer,

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[56] Bradley Guy, G. and Charles J. Kibert. 'Developing Indicators of sustainability: US Experience,' Building *Research & Information*, Number 26 Issue 1, 1998, p. 40.

[57] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.

[58] Environmental criteria can be prioritised from a variety of standpoints, for example: their significance to ecological impact in local, regional and global terms, and linkages and potential synergistic effects with others. Particularisation is likely to create specific clustering and emphasis between criteria within the tool, prioritising them against each other; therefore, whilst the benchmarks will provide the generic basis for the 'urban house in paradise', the tool will facilitate the process of prioritisation. The notion of prioritising assessment criteria is captured through the process of placing weightings upon them within the matrix, as a part of the methodology in establishing a single overall measure of performance.

[59] Wedley, William C. 'Combining Qualitative and Quantitative Factors - An Analytic Hierarchy Approach,' *Socio-Economic Planning Science*, Volume 24 Number 1, 1990.

determines the specific priorities between constitute elements.

Each of the drawn studies provides material through which an objective and measured analysis of each of the benchmarks can be tested; and, moreover, an analysis that can be conducted in terms of an interrelated tool, where each criteria has an effect upon the others. Other projects, selected from best practice in urban housing across Europe, will provide another source of material through which the tool can be tested and validated. The outcomes of that analysis can then be fed back into the tool and its values, to refine the model.

1.11 Analysis and Validation

Derived from a multitude of sources, both primary and secondary, the benchmarks are validated within the final drawn studies to ensure they are achievable, and not mutually exclusive. The assessment tool is validated through the drawn studies, specialist interviews and literature review; undertaking the validation from three independent directions increases confidence in its robustness.

The drawn studies form an integral part of the research methodology; Studies Six, Seven and Eight which follow the creation of the criteria, benchmarks and assessment tool are used to analyse the plausibility of the benchmarks and the tool within the reality of an architectural project. They utilise the tool as it would be used in the design of a new dwelling, ensuring it is kept related to, and not abstract from, the design process. Each Study is designed to embody the ideal benchmarks in a particularised form. The studies can then be analysed to determine the extent to which the ideal standards have been achieved, and therefore validate the proposed values, and also validate the interrelationship between each of the criteria and the other benchmark values. The analysis of the ideal genotype benchmarks as particularised studies will, therefore, determine firstly, if they are achievable, and secondly their potential cohesiveness, to determine if they are directly proportional, that one has a consequent benefit on another, and if any are mutually exclusive or inversely proportional; and then validate the magnitude of those consequential effects.

The validation through the drawn projects is complemented by specialist interviews of relevant parties, such as environmental engineers. This will determine the objective opinion of specialists to the tool itself and its methodology, and will identify strengths, weaknesses and possible revisions. A questionnaire is used as the basis for these interviews, in order that the process is consistent and objective, and that the views of the different specialists can be cross-referenced against each other.

The analysis through the drawn studies, the specialist interviews and the literature review combine to form a triangulated approach to the validation of the 'urban house in paradise' assessment tool. Undertaking the validation from three independent directions increases confidence in its robustness.

1.12 Measurability

The benchmarks provide an objective way in which to define the performance of dwellings. The assessment tool becomes the means by which a dwelling can be measured against the benchmarks of the 'urban house in paradise' at the design stage, and its performance refined. Through this measurability, it can be determined if the thesis is proposing innovative yet achievable performance in a northern European context.

Through the generation of numerically and critically valued benchmarks, the thesis will produce a qualitative performance specification for innovative and sustainable northern European urban housing, which will have been analysed and tested through the drawn studies.

Through the definition of values for each of the benchmarks and the analysis of the viability of these values through the drawn studies the thesis becomes measurable. One can, therefore, in an objective and scientific manner, determine whether or not it is successful in proposing innovative, yet potentially realisable, benchmark values that are relevant, as a holistic set, in terms of the individual aspirations of bodies such as the Movement for Innovation in a northern European context.

In terms of measurability, it is important to define what each criteria, each benchmark, is being measured against. Three existing assessment methods, the Building Research

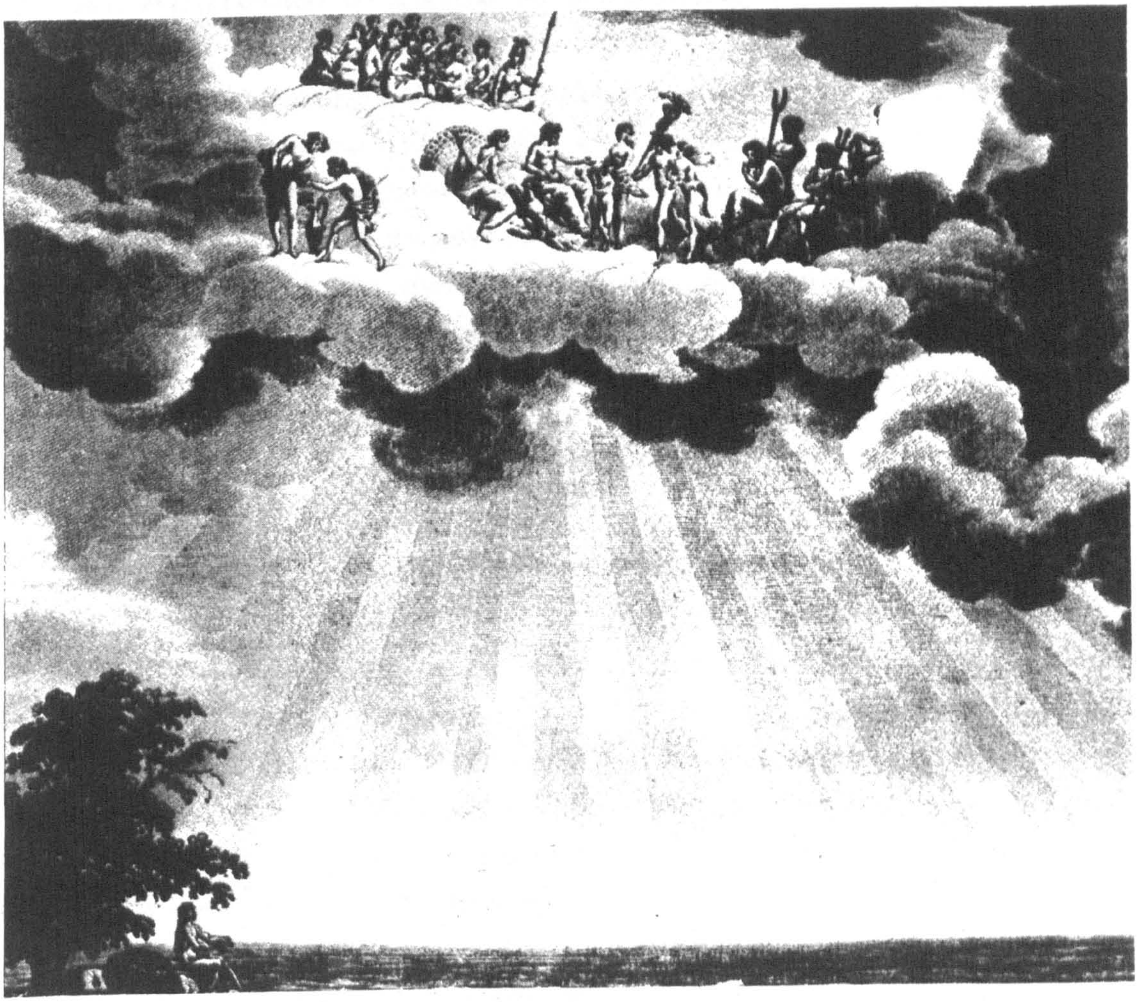
Establishment's *EcoHomes*, BEPAC and the Green Builder Programme, assign a point value to the various attributes of a building's performance. If the question is asked: what would be the cost of not achieving the ideal standards of the 'urban house in paradise', in what terms and units of magnitude is that cost definable and quantifiable? The *EcoHomes* assessment model considers the possibility of interpreting each criterion in terms of a common unit of measurement, but identifies difficulty in quantifying certain criteria into that common unit.[60] Therefore, it would be desirable to retain each specific unit of measurement for each of the criteria, as opposed to interpreting each criteria into one generic unit, and to devise a mechanism that will determine the consequential effects of each criterion across the units of measurement for all criteria.

The tool of assessment is the principal means through which measurability of projects can be conducted in terms of the benchmarks proposed. Refined through analysis of existing projects and the drawn studies, this model will determine the extent to which a given project achieves the ideal of the 'urban house in paradise' in terms of its position within the cohesive matrix of the paradisiacal benchmark standards developed in the first part of the research.

Having considered holistic issues facing the thesis, an evaluation of current environmental assessment methods was undertaken to identify any shortcomings that the criteria, benchmarks or tool for measuring the 'urban house in paradise' could attempt to overcome, to advance knowledge in this field.

[60] Refer to Annexe 1.0, An Individual Analysis of Existing Environmental Assessment Techniques, in volume 3.

Chapter 2



An Appraisal of Existing Modeling Techniques

2.0 An Appraisal of Existing Modelling Techniques

Having considered holistic issues facing the thesis, an evaluation of current environmental assessment methods was undertaken to identify any shortcomings that the tool for measuring the 'urban house in paradise' could attempt to overcome, to advance knowledge in this field. Such areas included longevity of the dwelling and lifecycle appraisal, interrelation linking criteria, reflecting holism that is a fundamental principle of sustainability, anthropocentrically focused assessment based upon human interest, and hierarchy between criteria.

2.1 Development of Environmental Assessment

Although environmental assessment was first developed thirty years ago, the assessment of buildings only came to prominence in the last decade; first generation assessment techniques have now reached a level of maturity sufficient to permit evaluation. Critical reflection of current models suggests attributes and qualities that new assessment methods can embrace; rather than evaluating each individually these are considered in terms of a wider intellectual framework.

The process of Environmental Impact Assessment (EIA), the evaluation of the effects upon the natural and man-made environment arising from general construction, was first developed in the United States of America thirty years ago; an outcome of the National Environmental Policy Act of 1969. Subsequent to this, in the context of increasing development, pollution and destruction of the natural environment, many countries have adopted and interpreted the US EIA process into assessment procedures of their own. Christopher Wood has compared seven EIA systems from an international context, including the United Kingdom's; within this text criteria are proposed for the evaluation of EIA models.[1]

The environmental assessment of buildings themselves first came into prominence in the early 1990s. Analysis of existing building environmental assessment models has identified some key limitations,[2] which include: lifecycle assessment, globalisation, the ability to be

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[1] Wood, Christopher. *Environmental Impact Assessment - A Comparative Review*, London: Longman Scientific & Technical, 1995, p. 12.
[2] Cole, Raymond J. 'Emerging Trends in Building Environmental Assessment Methods,' *Building Research & Information*, Number 26 Issue 1, 1998; and Curwell, Steve and Ian Cooper. 'The Implications of Urban Sustainability,' *Building Research & Information*, Number 26 Issue 1, 1998.

utilised as a design tool, and cross regional and national standardisation. In addition, existing models are largely 'feature orientated,' i.e. the assessment is made against a set of features which experience or general consensus has shown that the inclusion of which will contribute to lower environmental impact. Critical reflection of current models suggests that it is more desirable for further developments in assessment modeling move toward producing performance-related assessment.[3] The inadequacies and limitations that have been identified provide a focus from which second generation assessment models can be developed.

Existing models that can provide the background in which to establish the new assessment methods include:[4]

- Building Environmental Performance Assessment Criteria – (BEPAC)
- C-2000
- Danish Manual on Environmental Management in Project Design
- Dutch Environmental Preference Method
- Eco-Profile
- Eco-Quantum
- Environmental Standard and EcoHomes
- Envest
- Evaluation Survey Table of Global Environmental Impact
- Factor Four
- Green Builder Programme (Residential)
- Green Building Tool – (GB Tool)
- Housing Quality Indicators (HQIs)
- LEED
- The Absolutely Constant Incontestably Stable Architectural Value Scale
- United Kingdom Standard Environmental Assessment system

The following text presents an overall analysis of the positive and negative attributes of the principal examples of these assessment models. An analysis of each on an individual basis is contained within Annexe 1.0, An Individual Analysis of Existing Environmental Assessment Techniques. It is worthwhile to consider these precedents within an overall intellectual framework, rather than only considering the attributes of each in isolation to the others. This will give an indication of the relevance of each in the wider context of the historical and cultural evolution of dwelling, and to the evolution of wider ecological awareness, in particular the philosophy of Deep Ecology.

2.2 Scope of Assessments

There are two principle limitations to the scope of existing assessments.

[3] Curwell, Steve and Ian Cooper. Op. Cit.
[4] Sources for these assessment tools are varied, but include direct analysis of the tools themselves and, Cole, Raymond J. Op. Cit., 1998, p. 6.

Firstly attention tends to be focussed solely on the scale of the building, and not considering the wider impacts of its context. Secondly, most assessments focus upon a discreet part of a building's life span; a small number do recognise the significance of lifecycle to environmental assessment, however lifecycle assessment is relatively in its infancy.

Current building assessment techniques, such as the Building Research Establishment's (BRE) *EcoHomes* award and BEPAC, tend to focus attention solely toward the scale of the building, and thereby do not account for key parameters in defining environmental impact in the broader perspective of sustainable urban development; thus they contain serious inadequacies from the point of view of assessing a building's contribution towards holistic sustainable urban development. An admirable feature of the Housing Quality Indicator (HQI) assessment is that it does not view the dwelling as an isolated entity, but as a part of a wider development in terms of its surroundings and context; it was seen as important to relate a dwelling's design both to the way in which people wish to live and the context in which the dwelling is to be located.[5]

The scope of assessments also varies in terms of the period of a building's lifecycle that is studied; most focus upon a specific, discrete part of the building's life-cycle, and not its entirety. *EcoHomes*, for example, principally assesses the building during its period of inhabitation; it has no holistic appraisal of the lifecycle of a project, from extraction of materials, through construction and inhabitation, to deconstruction or demolition.[6] The Dutch Environmental Preference Method (EPM) considers the effects of materials throughout their life span, during extraction, production phases, building phases, occupational phase and decomposition. However, during building and occupational phases it considers only the impacts of materials, and not the total impacts of the building as a holistic entity. Some methods do recognise the importance of a lifecycle to environmental assessment, such as the Danish Manual on Environmental Management in Project Design, but which acknowledges that an overall approach, where environmental impacts, are evaluated over the whole life span are new fields of study.

2.3 Interrelation

Holism, taking account of cause and effect relationships within and between systems, is a critical factor in sustainability, yet it is a principle

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

omitted from virtually all environmental assessment methods. Where interrelation does exist, it is partial and does not consider the interrelated links between all criteria throughout the life span of the building.

Typical of existing models, *EcoHomes* assesses each dwelling against a set of criteria; the assessment is elemental, as opposed to holistic, in that each of the criteria is considered in its own right, without relation to any of the others. Although the Building Research Establishment's *EcoHomes* assessment model provides no crossover of information between each criterion, in terms of assessing the criteria against a common scale, it does acknowledge that it would be possible to use a common unit of measurement. Attempts have been made to develop a common basis for comparing and contrasting environmental issues and impacts, reducing the range of impacts to a single index, including: cost, equivalence method, ecological footprint and 'ecocost'.[7] This has lead to the development of Ecopoints, the Building Research Establishment's unit of environmental impact measurement, which is referred to later. 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 that *EcoHomes* lacks, but retaining individual units of measurement. As identified in the Introduction, 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 lack of a holistic approach is also a criticism of BEPAC. Through breaking down all of the criteria in the assessment 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.

The development of the EPM, 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 is intended to be complimentary to models such as BREEAM, the Building Research Establishment's Environmental Assessment Method, and *EcoHomes*, that consider the implications of the building in use in terms of, amongst other criteria, energy consumption,

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[6] Golton, Bryn. 'Sustainable Development, the 'Green' Agenda and Building'

[7] Cole, Raymond J. 'Prioritising Environmental Criteria in Building Design and Assessment,' in Brandon, P. S., P.L. Lombardi and V. Bentivegna. *Evaluation of the Built Environment for Sustainability*, London: E & FN Spon, 1997.

waste and pollution. This would be the only way in which such assessment methods could constitute a holistic analysis of a dwelling throughout its lifecycle.

Some of the latest environmental assessment methods attempt to link up aspects of a building throughout its lifecycle in pursuit of a holistic approach. For example, the Dutch Eco-Quantum assessment method[8] uses two independent programmes to determine the embodied impact of materials used, and the energy consumption during inhabitation; however, it does not create automated linkages between these two fields, and therefore the elegance and inherent advantages of an interrelated holistic assessment is lost.

As opposed to being an environmental assessment model, *Factor Four* represents a philosophy for more sustainable development proposing a doubling of the standard of living whilst consuming half of the resources that are used at present; it can be interpreted as a standard through which to judge an increased level of efficiency in resource consumption, and therefore can be looked upon as a benchmark. *Factor Four*, and increased resource productivity, requires the integration of parts to create a significantly more efficient whole.[9] Therefore, as a reflection of such integration, a matrix to measure such efficiency should consider all of the parts as an integrated whole, as oppose to individually. It is a wider scale approach, extending beyond the boundaries of an isolated focus upon, for example a dwelling, to encompass all aspects of productivity and consumption in the economy; therefore, in this sense, it is more holistic. In addition, it encompasses the socio-economic dimensions of sustainability through its focus upon the standard of living and well being.

2.4 Anthropocentrism

Despite the claim to be an environmental assessment, many methods focus either in the majority or in totality on impacts in terms of human interest. Some feature-orientated methods do consider impacts in solely in terms of the natural environment, but these are the exception rather than the rule.

Some assessment methods have a clearly identifiable anthropocentric emphasis, rather than the ecocentric one that underpins the philosophy of Deep Ecology. The Ecopoints rating, a single unit measurement of environmental impact developed by the Building Research Establishment, is derived using a series of weightings to determine the relative significance

[8] IVAM website, 22 July 2000: www.ivambv.uva.nl/IVAM
[9] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998.

of various parameters of environmental, economic and social sustainability.[10] Ecopoints are used in both the *EcoHomes* and *Envest* assessment models. Out of the most significant 16 parameters, 9 are based solely on human interest, including employment, education, health and security. Evidently this is not in harmony with a Deep Ecological approach to sustainability, which views the impacts on humans to be at most as significant as those on nature, when over half of the most significant parameters are concerned only with human interest. This is also true of the Danish Manual on Environmental Management in Project Design; in terms of assessing the effects of a building or structure, 17 criteria are dedicated to effects on human health, whereas only 11 assess effects on environmental health.

Whilst the EPM can be criticised for only considering material impacts during the construction and occupational phases of their lifecycle, the parameters for its assessment are based to a significant extent on the impacts upon the natural environment.[11] The assessment method developed by the American architect Malcolm Wells, The Absolutely Constant Incontestably Stable Architectural Value Scale, has the closest affinity to the philosophy of Deep Ecology. Criteria used as the basis for determining the impact of a building are based on a wilderness environment, the forest, and therefore only consider a building in terms of its impacts upon the natural environment.

2.5 Cultural and Vernacular Influences

Longevity, in terms of material permanence, is a part of the culture of dwelling, and also can have significant influence on the environmental sustainability of a building; related to this is the ability of buildings to be capable of adapting to accommodate new uses. Although it is recognised that it is crucial to consider environmental impacts at the design stage, visual design quality is rarely assessed.

Amos Rapoport suggests that contemporary vernacular design, a response to local culture, may be one based upon type, rather than form or materiality; he exemplifies this with the increased popularity for the apartment dwelling type for single people living in cities.[12] This trend is followed in the United Kingdom, and notably across Europe, in the present day.

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[10] 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.
[11] These impacts include: shortage of raw materials, ecological damage caused by extraction of raw materials, energy consumption at all stages (including transport), water consumption, harmful emissions, global warming and acid rain, and waste.
[12] Rapoport, Amos. House, Form and Culture, New Jersey: Prentice-Hall, 1969.

One of the primary causes of increased housing need is due to demographic change, with more young people living on their own and for longer, cohabiting later in life, and the increased number of elderly people. Research into preferences of distances for living from urban centres demonstrates that the youngest and oldest age groups prefer living more centrally than any others do.[13] This confirms a need for more single and two-person accommodation within cities, in addition to the fact that these two age groups are those which are a significant part of the cause of rising housing demand. Only GB Tool has criteria that assess the ability of a building to adapt and respond to new dwelling types, recognised by Rapoport as culturally representative.[14] In *EcoHomes* adaptability and flexibility are identified as criteria that may be considered over and above those in the assessment.

Longevity, in terms of material permanence rather than occupational, is a part of the culture of dwelling in a European context, although less so in the United States of America. In determining the lifecycle energy consumption of a building the Building Research Establishment's assessment of office buildings, entitled *Envest,* multiplies the annual energy consumption during occupancy by its predicted life span,[15] this value 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, and therefore the greater the perceived sustainability of the building. This is contradicts the assessment's original intention of drawing attention to the significance of embodied impacts[16] and could be interpreted as encouraging buildings with shorter life spans, as they are perceived as more environmentally benign; this might be construed as a detrimental impact on the longevity of buildings.

In his essay 'The Generic City' Koolhaas proposes that in the future the hotel will increasingly provide residential accommodation, implying greater temporality and less permanence.[17] 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 is considered as a representation of man's presence through time, and buildings, including dwellings, are a part

[13] Lindberg, Erik et al. 'Residential-Location Preferences Across the Life Span', *Journal of Environmental Psychology*, Issue 12, 1992.
[14] This is assessed in terms of adequate floor to floor height, appropriateness of core and structure location to adaptation, and ease of changing dwelling layouts to accommodate changing household requirements. Cole, Raymond J. and Nils K. Larsson. 'GBC '98 and GB Tool: Background', *Building Research & Information*, Volume 27 Number 4/5, 1999.
[15] A default value of 60 years is assumed, but this can be varied.
[16] Interview conducted with Jane Anderson of the Building Research Establishment's Sustainable Construction Unit, 16 August 2000.
[17] Koolhaas, Rem. 'The Generic City', in Koolhaas, Rem and Bruce Mau. *S, M, L, XL*, Rotterdam: 010 Publishers, 1995.

of the culture, spirit, theories and materials of the age, reducing longevity will hasten the obliteration of that representational legacy. Clearly, shortening the life span of a dwelling minimises the efficiency of the materials from which it is constructed, which can account for 10 percent of the energy consumed over the life span of a typical dwelling.

GB Tool includes the criteria for assessing adaptability under the heading of longevity; also included is a criterion demanding selection of materials with a level of durability appropriate to the planned service life of the building. However, no consideration is required to be given to maximising the period of that service life. Hence, longevity is only considered in the context of the planned life span of the building, and not maximising that life span.

Considerations such as cost and aesthetic value do not have any implication in environmental assessment or preference ratings. The only method in which aesthetic value constitutes a part of an appraisal is the HQI assessment.[18] Although it might be considered that any performance based assessment method will implicitly involve the concept of quality, this is also the only one which explicitly expresses it; a consequence of this is that parts of the assessment are subjective. In performance assessment a prerequisite should be continuity and consistency. However, during the pilot testing of the HQI methodology, different assessors rated the same project with different scores; this highlights the difficulty in integrating subjective qualities in performance assessment. Related to design, the Danish Manual on Environmental Management in Project Design recognises that environmental management should be considered at the briefing and design stages, to ensure that they are not an after-thought. In this way it can be used as a basis for decision-making in the design process, so that environmental planning can be integrated into work associated with defining a project and designing its solution.

The concept of integrating quality into an assessment is valid, but poses difficulties. In the final version the aesthetic value analysis in the HQI methodology is restricted to only visual impact, layout and landscaping of the site, and quality of light, aspect and prospect in the dwelling. However, it might be construed from a superficial interpretation of the term 'Housing Quality Indicator' that a high standard in other areas of aesthetic design will be attained if the HQI score is high. It should be implicit in any assessment tool that the overall quality of the dwelling will be improved as a consequence of increasing the measured performance, and that quality in areas beyond the scope of the assessment should not be compromised as a result. However, at the outset, an assessment tool should identify the

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

areas in which quality will be improved if the score it measures is increased.

The HQI assessment does not view the dwelling as an isolated entity, but as a part of a wider development in terms of its surroundings and context; This is particularly relevant if an assessment is to be orientated toward an urban site, where context is likely to be of greater significance than in greenfield sites. Ironically however, one of the Registered Social Landlords that pilot tested the HQI assessment felt that it under emphasised flats, particularly those 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.[19] 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.

2.6 Summary

The principal inadequacies of existing environmental assessments that have been identified are: that assessments are often anthropocentric; there is a lack of interrelation between criteria and longevity is infrequently and indirectly considered, both of which would encourage a holistic analysis of the building. Also, performance is frequently reduced to a singular score, which does not demonstrate the magnitude of specific improvements in environmental performance or provide wider incentives for those improvements.

To conclude, in terms of advancing environmental assessment tools already in existence, the following issues can be identified from the above analysis as areas that could be innovated upon, or developed in the first instance as new areas in the performance assessment of dwellings.

Longevity, in terms of maximising the life span of a building, is rarely considered as a parameter of assessment. Furthermore, in some examples minimising the life span of the building is in effect rewarded with a higher rating, attributing a perceived improvement in its overall sustainability. This approach does not maximise the efficient use of material resources and energy embodied in the building.

A philosophy of holism, taking account of cause and effect relationships within and between

[19] Ibid.

systems and considering effects throughout a lifecycle, is a critical factor in sustainability.[20] Contrary to this, there is an evident lack of interrelation between the criteria used within existing environmental assessment methods. Taking into account the consequential effects of criteria upon each other in an assessment might encourage a more holistic understanding of the overall sustainability of a dwelling or building, and would create a more responsive assessment methodology.

Sustainability, and in particular ecological sustainability, has issues beyond those relating solely to human interests. In some assessments there is a clear anthropocentric orientation, with emphasis on human-related criteria. A more Deep Ecological approach, in which the human is considered as at most equal to other species and ecosystems might result in a more even balance between anthropocentric interests, and the wider interests of the ecology of the planet as a whole.

Assessments such as *EcoHomes* and *Envest* quantify the outcome of an assessment in terms of a final, singular score. A disadvantage of quantifying the performance of a building in a relative, abstract score, as opposed to a quantitative profile of benchmarks, being that it is difficult to determine how the score was reached, and which aspects of the building's performance contribute beneficially or detrimentally to it. Also it gives no potential to perceive the wider benefits of creating a more sustainable dwelling, such a reduced energy consumption which will equate to reduced energy costs, and therefore does not maximise the incentive to do so.[21]

An assessment should be responsive to current agendas where they are relevant and do not compromise the philosophy that underpins it. For example, it would seem pertinent for the criteria that define the 'urban house in paradise' to embrace the current agenda for encouraging urban dwelling and the development of brownfield sites.

Having appraised current assessment methodologies, identifying any shortcomings or positive attributes, it was found that there is a lack of interrelation between criteria, longevity is infrequently and indirectly considered and assessments are often anthropocentric. The next stage of the research was to establish the criteria that define the 'urban house in paradise', which widen the scope to create a more holistic and effective

[20] Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995.
[21] This was recognised as a shortcoming of *Envest*'s methodology in an interview conducted with Jane Anderson of the Building Research Establishment's Sustainable Construction Unit, 16 August 2000.

evaluation of the dwelling, responding to the shortcomings of that have been identified.

Chapter 3

Criteria for the Tool

3.0 Criteria for the Tool

Having determined inadequacies of current assessment methodologies, the next stage of the research was to establish what the criteria that define the 'urban house in paradise' are, responding to the shortcomings of that have been identified. During this chapter, the criteria that will be benchmarked to create a generic performance profile of the 'urban house in paradise' are established. Prior to doing so, the scope that the criteria are intended to cover, and the philosophical background to the extent of that scope, is discussed.

3.1 Scope of the Criteria

The criteria that define the 'urban house in paradise' attempt to encompass all quantifiable aspects of a dwelling throughout its lifecycle. Some relate to the ecological sustainability of the dwelling, others to spatial design. Indirect issues, arising from the inhabitants of the dwelling, but beyond its boundaries, are not included.

Before establishing the criteria that define the 'urban house in paradise', it is crucial to identify boundaries to the scope of what they are to consider and assess; to establish confidence that the field is understood holistically, the edges of that field must be known. This will also create an awareness of what is, and is not, included in an assessment.

The criteria are intended to cover all direct, definable performance aspects of a dwelling throughout its life span. They will cover performance aspects relating to the spatial design of the dwelling, such as space standards and daylight. Following this in the lifecycle is realisation, starting with the materials from which it is constructed being extracted, and then during its construction. The performance of the dwelling will be considered throughout its period of inhabitation, including the longevity of that period; also included are the effects of the inhabitants whilst inside the dwelling that relate to its overall performance, such as the energy and water consumed whilst fulfilling the rituals of dwelling to the inhabitation. Finally the demolition of the dwelling will be considered.[1]

[1] It should be borne in mind that due to the interrelation between the criteria, they should not be considered as relating to only one specific period of the lifecycle. Taking insulation as an example, the depth of insulation specified at the design stage will affect the quantity of material used and therefore

Wider and indirect consequences arising from the household, such as car use, are not included. The first reason being that the thesis is focussing upon the dwelling and its site and context, rather than the lifestyle of its inhabitants; however, that is not to say that it is perceived as an isolated entity. Secondly the complexity in quantifying such aspects due to, for example, the potentially unpredictable nature of human behaviour is considered beyond the scope of the thesis. However, where such issues do arise within the defined scope they will be highlighted and the consequent impacts discussed, at least qualitatively.

3.2 Philosophical Background

The criteria are intended to be able to run parallel with the creative design process. Whilst they may inform it, it is not envisaged that they will impinge or have a detrimental impact upon it. They are generic; the realisation of the 'urban house in paradise' could be realised in many different forms.

The design process seeks a creative response to an identified need. The criteria and benchmarks of the 'urban house in paradise' are not intended to dictate that process, proffering a monistic approach to design; rather, they are intended to harmonise with it, to run in parallel or intertwine, like a DNA strand, informing but not impacting upon or dictating its direction. Architects have often based their work on a conceptual model;[2] if that model implies singularity, one might question its validity in a pluralistic world. The criteria and benchmarks are intended as a generic framework, and not to propose that there is any singular or specific embodiment of them. The 'urban house in paradise' could take many forms or incarnations; pluralism is inherent in a creative process. It is not intended that the set of criteria constitutes a pattern book,[3] a didactic influence on the creative process of designing a dwelling that aims to embody the performance of the 'urban house in paradise'.

Creativity emerges from a perpetual interaction between the response to physical context and intellectual, abstract concepts; the creative design evolves at the juncture where the

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the energy embodied in the dwelling's construction, and also the energy consumed by the dwelling during its period of inhabitation.

[2] Biswas, Ramesh Kumar (ed). *Innovative Austrian Architecture*, New York: Springer-Verlag Wien, 1996.

[3] Comparable to that of Christopher Alexander's *A Pattern Language*; Alexander, Christopher, S. Ishikawa and M. Silverstein. *A Pattern Language: Towns, Buildings, Construction*, Oxford: Oxford University Press, 1997.

concept merges with the qualities of a place. The individual building develops in a specific place, whereas environmental assessment is conceived in abstract space. The assessment tool of the 'urban house in paradise' aims to provide the methodology for bridging the gap between a particularised place and the criteria that have been conceived in abstract space, through which global thinking on environmental impacts can be integrated into local action, and environmentally sustainable measures can be developed that are compatible with creative design. The drawn studies, as an integral part of the research, are intended to demonstrate this process.

Furthermore, the framework is not prescriptive in a mandatory sense, proposing a level of performance required to be achieved. Criteria and benchmarks are proposed that, if achieved, will result in a dwelling that the objective, quantitative performance of which will be innovatory in terms of standards of best practice in a northern European context. It does not, therefore, propose a monistic approach to the design process. This may be another justification for using the term ' the urban house in paradise', rather than 'utopia'; with its inherent political implication the latter might be construed as dictatorial.

3.3 Sources, Stocks and Flows

A number of sources were used in determining the criteria, to ensure that they are holistic. Existing environmental assessment methods were studied to determine criteria that are already considered. The drawn studies identified new criteria. To assist in ensuring that the dwelling has been considered holistically throughout its lifecycle, a stocks and flows diagram was drawn.

The matrix of criteria that will constitute the 'urban house in paradise' have been derived from a multitude of sources. The process of selection has been governed by the ambition of deriving a set of characteristics that will define the performance of a dwelling, encompassing all aspects of its lifecycle. As has been established, the holistic approach to the criteria is critical, as it is a fundamental parameter of sustainability. For this purpose, a stocks and flows diagram of a dwelling was drawn up. The diagram can be used to determine the resources embodied within and flowing through the dwelling throughout its lifecycle, and can be expanded to consider the impacts of each stock and flow. The diagram assists in creating a holistic picture of the dwelling, and to ensure that any criteria or impacts are not being double counted. The stocks and flows diagram for a dwelling is shown overleaf.

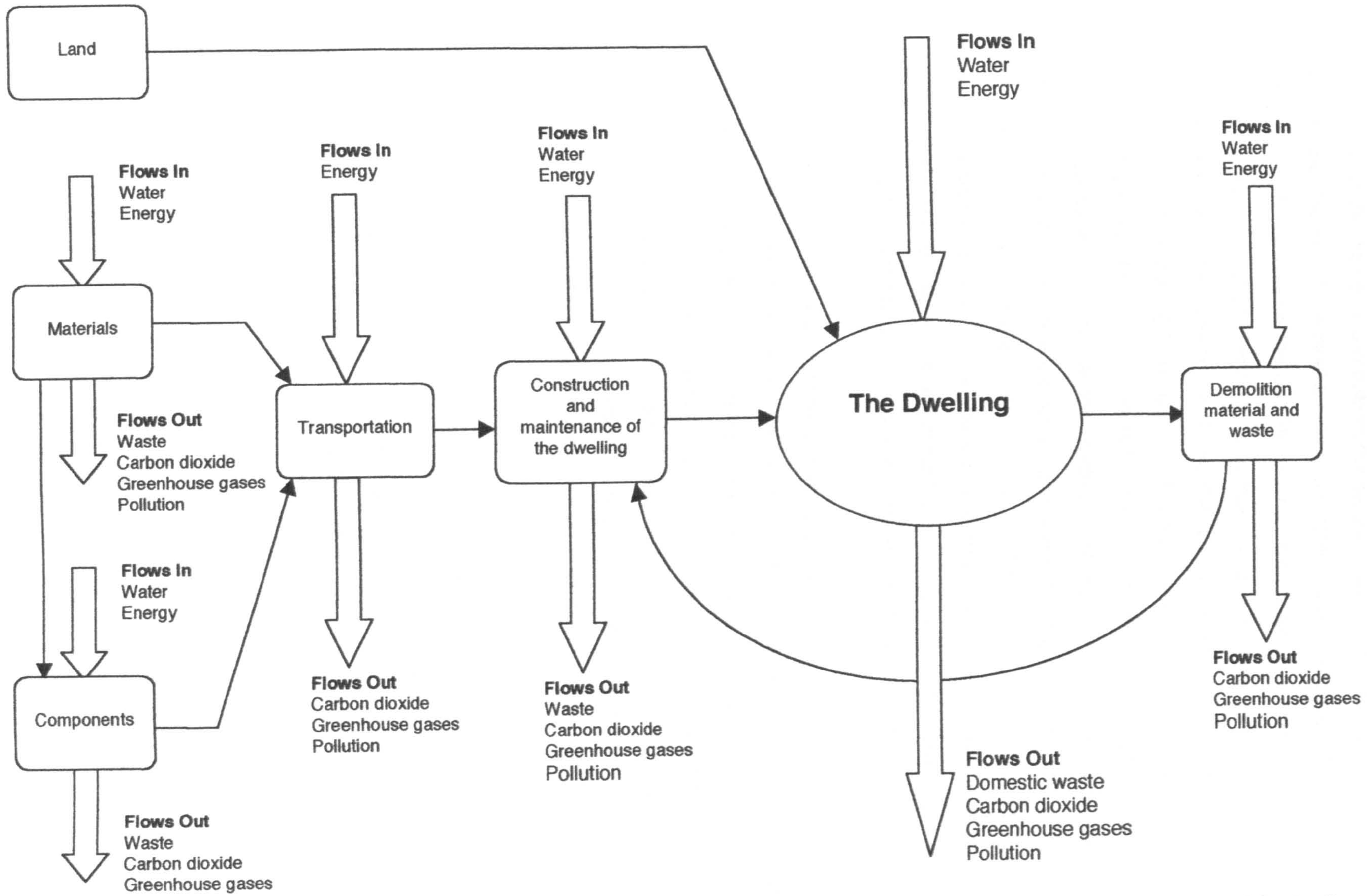

Figure 4: Stocks and flows of the dwelling

Stocks, such as materials used to construct the dwelling, are located at the left-hand side of the diagram; the lifecycle of the stocks runs horizontally across the page. The flows, such as energy, which flows through the dwelling during its occupation, run vertically down the page. The diagram assists is identifying resource use and impacts associated with each stage of the life cycle of the dwelling. It shows that it is not only the dwelling that has flows through it, and that stages along the cycle of realising the dwelling also have flows of energy and resources through them. For example, the construction and maintenance of the dwelling requires materials, and that the production of those materials, a stock, also has flows of energy through it, and that the construction itself also has associated flows, such as energy and water. Each of the flows, particularly if it is through a process, such as construction, typically results in both waste and, if energy is being consumed, pollution. The strong linearity of the stocks and flows throughout the lifecycle of the dwelling is clearly evident, broken only by the recycling of materials at the end of the dwelling's life span.[4]

Determining the criteria has also involved literature review, a *tour d'horizon* of comparative assessment models and contemporary research on defining the performance of buildings, some of which were explored in the previous chapter. This process has then extended into defining the benchmark values for the criteria, which will be discussed in the next chapter. Extensive literature studies of best practice housing projects on a European scale have also been undertaken to determine the criteria that are used to define their performance; this has also been valuable in determining the performance characteristics for a variety of urban dwelling types.[5]

Drawn Studies 1 to 5 have served as exploratory material to assist in determining critical issues in defining performance, in particular in defining new criteria, covering aspects of performance not covered in existing work. These are criteria that have emerged as relevant during the design process. The criteria of the Urban Housing Design and Procurement

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[4] Increasing the ecological sustainability of the dwelling will require increasing the cyclic loop, and minimising the linearity identified.

[5] For example, the Building Research Establishment's *General Information Report 38*, of ultra low energy dwelling in the United Kingdom and Europe, covers a range of dwelling types from the individual dwelling, to terraced units, to multi-occupancy blocks of flats. The criteria contained within this document were, therefore, appropriate to each of these dwelling types. BRECSU. 'Review of Ultra Low Energy Homes – A Series of UK and Overseas Profiles,' *General Information Report Number 38*, London: HMSO, February 1996.

Database, the selection of which was an integral part of the early stages of this study, have been reviewed to derive those that are performance based.[6]

3.4 The Criteria

The definitive set of criteria that collectively define the 'urban house in paradise' is composed from a primary collective of secondary material and original research, through the drawn studies and stocks and flows analysis. They are presented in the list below.

The set of criteria that collectively and comprehensively define the 'urban house in paradise' has been synthesised from a multitude of sources. These include an extensive literature review of existing assessment methods, and original work such as the stocks and flows analysis which considers the dwelling throughout its lifecycle, and the drawn studies, which consider the performance aspects of a dwelling that arise through the design process. The outcome of this process is a symbiotic range of criteria. The following presents, alphabetically, these criteria, which are considered as critically relevant to defining the holistic performance of sustainable urban housing, and to which potential benchmark values will be defined:

CO_2 emissions: inhabitation (kgCO_2 per m^2per annum)
CO_2 emissions: on site construction processes (kgCO_2 per annum)
carbon intensity: space and water heating (kg per kWh)
construction period (weeks per dwelling)
contextual significance of the site
deconstruction and demolition: recycling of materials
density: quantitative (dwelling per ha)
density: qualitative
design life span (years)
diversity: programme (functions per ha)
domestic waste recycling (kg per household per day)
ecological significance of the site
ecological weight: embodied energy (kWh per m^2)

[6] A full list of the Urban Housing Design and Procurement Database (UHDPD) criteria is contained in Annexe 4.0, refer to volume 3.

ecological weight: embodied CO_2 emissions ($kgCO_2$ per m^2)
energy consumption: on site construction processes (kWh per m^2)
energy consumption: inhabitation(kWh per m^2 per annum)
energy generation: inhabitation (kWh per m^2 per annum)
green space
lifecycle cost (£ per m^2 or £ per m^3)
nitrogen oxide emissions from gas boilers (mg per kWh)
other ecological impacts of materials
other greenhouse gas emissions (kg per m^2 per annum)
pollution from energy consumption during inhabitation (g per kWh)
procurement strategy
quality of internal environment: indoor pollution
quality of internal environment: daylight (average daylight factor)
quality of internal environment: ventilation and air-tightness (air changes per hour)
recycling of construction waste
recyclability of building and adaptability
space standards: area (m^2 per inhabitant)
space standards: volume (m^3 per inhabitant)
thermal performance (W per m^2 per K)
use of recycled materials
use of renewable raw materials
utilisation of local resources
water consumption: construction (litres per m^2)
water consumption: inhabitation (litres per household per day)

Each of the criteria are considered individually in Annexe 2.0, refer to volume 3. A description as to what the criterion assesses, and the reasoning and source behind its selection for being included in the criteria that define the 'urban house in paradise' is given.

3.5 Subjective Criteria as an Accompaniment to the Tool

The criteria are almost without exception objective, and can be quantitatively valued; they are intended to be independent of the creative design process. As an accompaniment to these a set of subjective criteria was developed which could form the basis of an assessment of the design quality of the dwelling. These are not

included in the criteria of the assessment tool as they might impinge upon the design process; it is envisaged that the tool is used internally within a practice, without recourse to external evaluation.

The criteria that have been developed for the matrix are purely performance based, and thus largely are independent of the design quality of the dwelling as a work of architecture; the only exceptions to this is the potential impact of the Contextual Significance of the Site and Density: Qualitative benchmarks. Therefore, as an accompaniment to the performance-based matrix, a set of design-based criteria has been developed; this would provide a methodology for undertaking an assessment of the design quality of the dwelling, as well as its performance. These two could be combined after assessment to provide an overall rating for the dwelling. Assessing design value is inherently a subjective process; the criteria that have been established are qualitative, as opposed to the predominantly quantitative performance benchmarks. Therefore whilst the criteria could be used by the designer as a guide during the design process, the actual assessment would be conducted by peer review, whereas it is intended that the performance-based assessment can be used as a tool by the design team during the design process.

In Annexe 4.0, refer to volume 3, is a list of the criteria that was developed as a general way in which to analyse urban dwelling projects, rather than a purely performance driven assessment. The subjective criteria are intended to be used by a peer panel to determine the design value of a project. These subjective criteria could be used in conjunction with those identified for the tool to create an assessment that combines both ecological and design value. Like the criteria of the 'urban house in paradise', it is not intended that these criteria encourage any particular design response, and not to inhibit the creative design process. They only serve as a potential framework in which to assess design quality.

These subjective criteria are not included in the criteria of the assessment tool for a number of reasons. Firstly, the tool does not intend to restrict the freedom of the design process, and including them may focus that process toward the criteria being assessed, and not responding to other influences that might drive or direct a creative response. Secondly, it is intended that the tool can be used internally within an architectural practice to determine the performance of the dwelling, against the proposed benchmarks, throughout the evolution of the design; as the subjective assessment would require review by an independent peer panel, including them would compromise this intention. This is also a shortcoming of some existing environmental assessment methods, such as the Building Research Establishment's *EcoHomes*, which require an independent assessor to conduct an assessment. The subjective criteria are only included as a suggestion as to how design quality might be incorporated into part of a wider appraisal of a dwelling project, possibly extending the limited scope of the assessment of architectural value in the current Housing Quality Indicator method, reviewed in Chapter 2.0 and Annexe 1.0.

With the individual criteria that collectively describe the 'urban house in paradise' identified, as those in existing assessments were inadequate in their scope, the next stage is to determine benchmarks for each. These values will define its holistic performance quantitatively.

Chapter 4

Benchmarking the 'Urban House in Paradise'

4.0 Benchmarking the 'Urban House in Paradise'

With the criteria that define the 'urban house in paradise' in a generic form established, the next stage of the research was to develop a series of benchmarks for each of the criteria. These are the way in which the standard of performance of the 'urban house in paradise' is established and communicated. Comparative values are also determined; these will demonstrate the standard of performance achieved by firstly a typical 3 bedroom semi-detached dwelling built in the United Kingdom to current regulatory standards, secondly a European comparison as an example of best practice, thirdly one of the drawn studies. Finally a standard for the 'urban house in paradise' is proposed.

4.1 History and Philosophy of Benchmarking

As a process for driving continuous improvement, to maintain a competitive edge, benchmarking has been used in other industries within the West for twenty years. The aim is to perpetually improve performance against best practice, the evaluation of which requires a comprehensive understanding of the relevant industry.

Whilst it is generally considered that the process of benchmarking originated in Japan, as a methodology for researching and assessing performance and sustained improvement benchmarking was first formalised into a recognised process in the West by the American company Xerox.[1] In the early 1980s the reprographics industry, of which until that time Xerox had been the undisputed leader of, was overwhelmed by Japanese competitors; within two years its market share had fallen by 80 percent. In order to regain its competitive edge Xerox developed a process of analysing the performance of its competitors' products, such as the number of components and differences in technology and efficiency; this provided standards that Xerox had to aim at. Having determined the level of their competitors' performance, Xerox could analyse their supply chain, manufacturing systems and their procurement methods, to identify how these targets could be reached.[2] David Kearns, chief executive officer of Xerox, established the formal definition of benchmarking as a process in the manufacturing industry:

Benchmarking is the continuous process of measuring products, services and

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[1] Zairi, Mohamed. *Benchmarking for Best Practice – Continuous Learning Through Sustainable Innovation*, London: Butterworth Heineman, 1996.

practices against the toughest competitors or those companies recognised as industry leaders.[3]

In 1991, the author Robert Eccles indicated the future significance of benchmarking, writing that, "Within five years, every company will have to redesign how it measures its business performance."[4] In the United Kingdom, from a slow start in the early 1990s, by 1993 a survey revealed that one third of the top companies were benchmarking their performance; by 1996 it had become the third most popular management tool, and began to attract interest from the Government, manifest in increasing reference to the importance of benchmarking in a series of *Competitiveness* White Papers. The European Commission supported a number of initiatives to support benchmarking at a European level.[5]

Benchmarking is a technique for driving continuous improvement in a product or process against best practice; the ambition of the benchmarking process is to perpetually achieve measurably improved performance. In essence this process involves the following stages: it commences by analysing one's current level of performance, and proceeds by identifying an external standard by which that existing performance can be measured, establishing a target value based on best practice. The next stage is to learn from what best practice is doing to achieve that standard, and finally to adapt one's practices to what has been learnt.

> "The overriding objective of benchmarking is to identify best practice, and compare performance with that standard."[6]

Benchmarks themselves are metrics, dimensional values, which quantify or qualify the performance of a product or process; they demonstrate that a certain level of capability is achievable and initiate questioning and investigation as to how that standard can be achieved by others. To evaluate best practice, establishing them requires a comprehensive understanding of current state of the relevant or appropriate industry.

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[2] Codling, Sylvia. *Benchmarking*, Hampshire: Gower Publishing Limited, 1998.
[3] Quoted in Camp, Robert C. *Benchmarking – The Search for Industry Best Practices that Lead to Superior Performance*, Milwaukee: ASQC Quality Press, 1989, p. 10.
[4] Eccles, Robert G. 'The Performance Measurement Manifesto', *Harvard Business Review*, January-February 1991, p. 131.
[5] These initiatives included the World Class Standards Network and Framework for European Benchmarking. Codling, Sylvia. Op. Cit.
[6] McNair, C. J. and Kathleen H. J. Leibfried. *Benchmarking – A Tool for Continuous Improvement*, New York: Harper Collins Publishers, 1992, p. 19.

4.2 Benchmarking within the Construction Industry

Recently benchmarking has begun to be used within the construction industry. Perhaps unwittingly initiated by Latham and subsequently Egan, it is being implemented by the Movement for Innovation and the Construction Best Practice Programme, and demonstrated through the Millennium Community Competitions. A commonality between all these is that the benchmarks are proposed as abstract percentages, and not quantitative, dimensional values.

Benchmarking, a tradition within other industries, has recently begun to be used within the construction industry to measure both performance within an organisation over time, and between organisations and the national average. When Michael Latham[7] proposed 30 percent improvements in productivity in the industry,[8] this was a benchmarked improvement in performance; when the Construction Task Force proposed, amongst others, 10 percent reductions in both capital construction cost and time year on year,[9] these were benchmarks for continual improvement. These two documents, and in particular the latter, were the genesis of the emerging culture of benchmarking in the construction industry. Following the publication of the Construction Task Forces' report, *Rethinking Construction*,[10] the Movement for Innovation (M^4I) and the Construction Best Practice Programme (CBPP) were both established with the specific intention of facilitating the benchmarked improvements identified in *Rethinking Construction* in the performance of the construction industry, and explicitly within that the house building industry.

The CBPP created a series of Key Performance Indicators (KPIs), which are supported by the M^4I, against which to benchmark the performance of specific criteria within the construction industry. These would act both as drivers for change and as a framework to 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. They are intended as standards against which individual organisations or companies can benchmark their performance against the industry average; although not, as is implicit in the philosophy of benchmarking, best practice. Zairi's general characterisation of companies that do not adopt benchmarking has remarkable similarities to the current state of the construction industry, as identified by

[7] Chairman of the Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry.
[8] Latham, Michael. *Constructing The Team: Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry: Final Report*, London: HMSO, 1994.
[9] The Construction Task Force. *Rethinking Construction*, London: HMSO, July 1998.
[10] Ibid.

Egan: "Internally focussed, without a clear understanding of their strengths and weaknesses, a reactive approach to competitiveness and a poor knowledge of customers' true requirements. Feeble efforts to innovate."[11]

It is perceived by the CBPP that the agenda established by *Rethinking Construction* can lead toward more sustainable development. For example, it is considered that reduction in capital cost will equate to less construction material, and therefore embodied energy consumption; a reduction in construction time will equate to less noise, disruption and visual intrusion; that reducing defects on hand-over will equate to less rework, and therefore less wastage in materials and energy; and that reducing accidents will equate to better quality of life for construction workers.[12] However, there is no certainty that a 10 percent reduction in construction cost will be achieved directly through, or equate to, a reduction in materials, and therefore embodied energy consumption. Clearly, to ensure that such improvements in sustainability are realised, these benchmarks would need to be accompanied by others that ensure targeting cost reduction includes ways that contribute to the sustainability of the building. Then moving beyond that, ensure that a deeper level of sustainability is achieved than would be created purely through, and almost as a consequence to, a cost driven approach.

Both of the Millennium Community competitions, in Greenwich and Allerton Bywater proposed benchmarked improvements in performance. These included aspects such as: construction cost, construction time, embodied energy, energy during inhabitation, CO_2 emissions and domestic water use. These projects are seen by the Department for the Environment, Transport and the Regions, who initiated them, as progenitors for the implementation of the *Rethinking Construction* agenda by the construction industry.

Common to all of these benchmarks is that currently they are typically proposed as abstract percentage reductions of an undetermined or undisclosed base value. This brings uncertainty to translating these values into practice. Benchmarking is a way in which to incrementally, but continually, improve the sustainability of dwellings. Cole considers that within an assessment of sustainability the evaluation should be directed at identifying the absolute amount of energy and mass flowing through a building.[13] Both of these factors qualify the ambition of the thesis to propose benchmarks for the 'urban house in paradise' that are quantitative, dimensional values.

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[11] Zairi, Mohamed. Op. Cit. p. 35.
[12] Construction Best Practice Programme website, 1 May 2000: www. cbpp.org/themes/suscon
[13] Cole, Raymond J. 'Building Environmental Assessment Methods: Clarifying Intentions', *Building Research and Information*, Volume 27 Issue 4/5, 1999.

4.3 Benchmarking the Criteria of the 'Urban House in Paradise'

Quantitative benchmarks were established for each of the criteria identified in the previous chapter; these constitute a way in which to define the performance quality of the 'urban house in paradise'. The values proposed innovate upon European best practice, and are informed by principles of sustainability such as Factor Four, reducing resource consumption to one quarter of its current level. It is considered that such reductions should be over and above the predicted increase in dwelling numbers.

The purpose of the benchmarking process is to determine quantitative values for the performance criteria of the 'urban house in paradise' that have been identified in the previous chapter. An aim has been, wherever possible, to define quantitative, rather than qualitative, values; this is due to the fact that quantitative values are more easily defined and assessed than qualitative ones, making the application of the benchmarks into practice more readily achievable.

The quantitative benchmarks of the assessment tool are a way in which to define quality; performance and ecological quality as a parallel, and certainly not at the expense of, architectural design quality. The analysis and methodology of assessment that underpins each of the benchmarks, and the proposed values for each of the individual criteria, are contained within Annex 3.0, refer to volume 3; the values proposed are collectively presented in a table overleaf. As the process of benchmarking is intended to encourage continual improvement, the use of 'greater than or equal to', ≥, and 'less than or equal to'', ≤, symbols indicate whether increasing or decreasing the value would constitute an improvement in the performance of the 'urban house in paradise' for each of the benchmarks.

A diverse range of sources has been used to determine these benchmarks. It has been the intention that the values represent performance standards that are highly innovative, whilst being technically achievable. The benchmark values are based on: firstly, the performance of a typical dwelling built to current regulatory standards, which provides the control benchmark; secondly a European comparative derived on the basis of evidence from research and best practice; thirdly the performance of one of the drawn studies that have been a part of the research methodology. Finally, emerging from these previous three and the extensive literature review involved in determining them, an 'ideal' benchmark based on advancing best practice in a northern European context was established.

Criteria		Benchmarks			
		Typical spec	European comp	Drawn study	u h in p'
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		50.4	15.9	23.9	≤10.4
CO2 emissions: On Site Construction Processes: kgCO2.m-2		54	13.5	34.6	≤27
Carbon intensity: kg.kWh-1		0.3	-	0.24	≤0.24
Construction period: weeks per dwelling		12	0.5	4	3
Contextual significance of site: Qualitative		No	Yes	Yes	Yes
Deconstruction and demolition: Recycling materials: Percent		33	80	50	≥85
Design life span: Years		60	200	100	120
Density:	quantitative: p.ha-1	<100	378	350	≥370
	qualitative	No and No	Yes and Yes	Yes and Yes	Yes and Yes
Diveristy: programmes.ha-1		1	41.6	53	50
Domestic waste:	refuse: kg.p-1.wk-1	8.7	-	4.7	≤2.4
	recycled: kg.p-1.wk-1	0.6	-	4.7	≥7.2
Ecological significance of the site: Percent and qualitative		47, No	100, Yes and Yes	100, Yes and Yes	100, Yes and Yes
Ecological weight: embodied energy: kWh.m-2		1,000	250	640.6	≤250
Ecological weight: CO2 emissions: kgCO2.m-2		360	90	262.6	≤90
Energy consumption: construction: kWh.m-2		150	38	96.1	≤75
Energy consumption: inhabitation: kWh.m-2.a-1		194	32	41.0	≤25
Energy generation: kWh.m-2.a-1		0	9.2	0.0	≥25, or ≥ c'smpt'n
Green space: Percent		196	21	237	20
Lifecycle cost:	Construction: £.m-2.a-1	9.87	7.68	5.06	≤4.44
	Energy: £.m-2.a-1	11.15	7.39	7.76	≤7.96
	Water: £.p-1.a-1	208.28	0	335.53	≤97.85
Nitrogen oxide emissions: mg.kWh-1		153	81	70.0	≤60
Other ecological impacts of materials: Qualitative, g.kWh-1		C	-	A	A, ≤6.596
Other greenhouse gas emissions: g.kg-1		0, 140	0, 0	0, 0	0, 0
Pollution: energy consumption inhabitation: g.kWh-1		2.002	3.843	6.494	≤1.004
Procurement strategy: Qualitative		Comp T, Lump sum	-	Competition	Performance spec
Quality of internal environment:	indoor pollution: Qualitative	No	No	Yes	Yes
	daylight: living, kitchen, beds: Percent	2.4, 1.5, 1.6	4.0, 2.1, 2.9	4.6, 1.9 3.4	≥ 5, 5, 3.5
	ventilation: ac.h-1	15	0.5	0.6	0.45
	airtightness: ac.h-1 at 50 Pa	15	0.17	2.0	≤0.17
Recycling construction waste: Percent		10	2	5.0	≥2.5
Adaptability: Internal loadbearing walls: Internal walls		0.8	0	0	0
Space standards: Area	1 person: m2.p-1	-	28	n/a	≥32
	2 persons: m2.p-1	22.4	25	n/a	≥27
	3 persons: m2.p-1	17.5	21	n/a	≥22
	4 persons: m2.p-1	16.0	19	18.9	≥19.7
	5 persons: m2.p-1	16.8	19	19.6	≥19.7
	6 persons: m2.p-1	17.2	20.5	n/a	≥20.4
	7 persons: m2.p-1	19.0	-	20.3	≥21
	8 persons: m2.p-1	20.3	-	n/a	≥21.7
	9 persons: m2.p-1	20.5	-	n/a	≥21.9
	10 persons: m2.p-1	19.7	-	n/a	≥20.9
Space standards: Volume	1 person: m3.p-1	-	75.6	n/a	≥96
	2 persons: m3.p-1	52.6	67.5	n/a	≥81
	3 persons: m3.p-1	41.1	63	n/a	≥66
	4 persons: m3.p-1	37.6	53.2	55.3	≥59.1
	5 persons: m3.p-1	39.5	49.5	57.6	≥59.1
	6 persons: m3.p-1	40.4	55.7	n/a	≥61.2
	7 persons: m3.p-1	44.7	-	60.9	≥63.0
	8 persons: m3.p-1	47.7	-	n/a	≥65.1
	9 persons: m3.p-1	48.2	-	n/a	≥65.7
	10 persons: m3.p-1	46.3	-	n/a	≥62.7
Thermal Performance:	Roof: W.m-2.K-1	0.25	0.09	0.14	≤0.08
	Exposed walls: W.m-2.K-1	0.45	0.14	0.14	≤0.12
	Ground and exposed floors: W.m-2.K-1	0.45	0.16	0.20	≤0.13
	Windows and rooflights: W.m-2.K-1	3.30	0.70	2.90	≤0.80
	Opaque outer doors: W.m-2.K-1	3.30	0.55	3.0	≤0.55
Use of recycled materials: Percent		0	50	50	75
Use of renewable raw materials: Percent		0	100	-	100
Utilisation of local resources: km		-	56	-	45
Water consumption: construction: l.m-2		34.1	-	9.5	8.5
Water consumption: inhabitation:	potable: l.p-1.d-1	160	0	155	6.5
	rain and grey: l.p-1.d-1	0	34	5	≤35.3
	total: l.p-1.d-1	160	34	160	≤41.8

Table 1: Benchmarks of the 'urban house in paradise'

Whilst efficiency, in terms of energy consumption and embodied energy for example, is undeniably desirable, it would not necessarily provide the solution to sustainability on its own. Efficiency cannot ensure the route to the reduction of resource consumption; it can prolong the life of a finite resource, but only providing that the reduced consumption of one sector is not outweighed by the growth of the scope of that sector, or by other uses. The imperative toward sustainability of the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, or the Earth Summit as it is more commonly known, demands a drastic reduction in resource consumption.[14] To make any impact upon resource consumption, clearly the rate of increased efficiency in a particular use sector must outweigh the rate of growth of that use sector.

To ensure that the proposed benchmarks of increased efficiency and reduced emissions of the criteria that relate to resource use are well in excess of the rate of increased household growth that is prevalent in England and elsewhere, and therefore should contribute to reduced resource consumption, it is necessary to determine the rate of household growth. In the White Paper 'Household Growth: Where Shall We Live?', the projection was made of the need for 4.4 million new dwellings in England between the years 1991 and 2016.[15] In the 1991 Census of Great Britain, the total number of households existing in England was 18,765,583. From these two pieces of information, the rate of growth of households in England will be 23.4 percent by the year 2016; this figure can be generalised, assuming for the purposes of this thesis that this growth is linear, to be a growth rate of 0.9 percent per annum. The Department of the Environment, Transport and the Regions subsequently revised these predictions of new housing need in 1999. The total number of new households in the twenty-five year period between 1996 and 2021 was predicted to be 3.8 million.[16] From a base level of 20.2 million households in 1996, this is an increase of 18.8 percent by 2021, an increase of 19 percent or 0.8 percent per annum. Therefore, the benchmarks proposed for the matrix should ensure a rate of increased efficiency and reduced consumption and emissions well above 1 percent per annum; or that a level of reduction well in excess of 19 percent is achieved by the year 2021, twenty years from the date of completion and submission of this thesis.

The philosophy of *Factor Four* proposes that resource consumption should be cut to one

[14] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998.
[15] Department of the Environment. *Household Growth: Where Shall We Live?*, presented to Parliament by the Secretary of State for the Environment, London: HMSO, 1996.
[16] Department of the Environment, Transport and the Regions website, 2 July 1999:
www.housing.detr.gov.uk/information/keyfigures/index.htm

quarter of its current level, or to half its level if the standard of living is doubled. "We can accomplish everything we do today as well now, or better, with only one quarter of the energy and materials we presently use."[17] Assuming that the standard of new dwellings remains relatively consistent, disregarding the increase in space standards proposed by the matrix of benchmarks as a desirable advantage over and above the reduction of resource consumption, and therefore accepting the challenge of a 75 percent reduction in resource use, in terms of *Factor Four* this reduction will have to be over and above the increased efficiency that will account just for the growth rate of new dwellings. Achieving a reduction of a factor of four in resource use over and above the growth in housing numbers identified above would demand a cut in resource consumption by 94 percent of current levels by 2021.

In the context of a growth rate of less than 1 percent per annum, the impact that new dwellings can have on the national consumption and emissions arising from the domestic sector as a whole may seem relatively insignificant. However, this must be viewed in the context of the long-term need for the stabilisation of the climate and ecology of the planet. Dwellings constructed after the turn of the century may account for 16 percent of the total housing stock by 2020, and as much as 25 percent by 2050.[18] In addition, whilst the potential exists to improve the performance standards of existing dwellings, this is significantly less than the potential improvements that could be made by an innovative approach to the standards of new dwelling design and construction. This factor is of particular significance in the England where the growth rate pertains to; however it can be assumed that the growth rate in other parts of the United Kingdom is of a factor comparable to that of England.[19] The number of new dwellings required is predicted to be significantly higher in the United Kingdom than in other European countries. The table overleaf portrays the rates of household growth per annum of several European countries:[20]

[17] Weizsaker, Ernst von, Amory B. Lovins and L. Hunter Lovins. Op. Cit., p. xxi.
[18] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.
[19] Department of the Environment, Transport and the Regions. *Our Towns and Cities: The Future – Delivering an Urban Renaissance*, London: HMSO, November 2000.
[20] The housing need figure for England was derived from the Department of the Environment, Transport and the Regions website, 2 July 1999: www.housing.detr.gov.uk/information/keyfigures/index.htm. The figures for other European countries were established through personal communication the relevant government body for each country: Danish Ministry of Housing & Urban Affairs, Finnish Ministry of the Environment, Dutch

Country	Projected Housing Need (Dwellings per annum)	Percent of Existing Number of Households (percent)
Denmark	- 2,920	- 0.1320
England	152,000	0.7600
Finland	28,875	1.3456
Netherlands	65,000	1.0110
Norway	18,677	1.0187
Sweden	25,000	0.6742

Table 2: Projected housing need in selected European countries

This clearly demonstrates that the total number of new dwellings required in England is significantly above that of other European countries, although as a proportion of the existing population the demand is one of the lowest. Therefore, to have an effect on the reduction of resource use, the proposed benchmarked values of increased efficiency will have to be highest for the United Kingdom. Should these benchmarks be applied directly to European housing construction, rather than adapting them to reflect the lower growth rates, then clearly there will be greater benefits to reduced resource use.

During the period between 1980 and 1990 the total number of households in Europe rose from 167 million to 183 million. The cause of the increase in housing need in England and across Europe is also pertinent.[21] Only two thirds of the increase in dwelling numbers in Western Europe was due to natural population increase, the remainder was caused by the splitting of family units. The average size of each household during that period fell from 2.9 to 2.7 inhabitants. Of the 3.8 million new dwellings required in England by 2021 2.7 million, 70 percent, are single-person households; by that time 35 percent of households will be one person living alone.[22] Smaller households use energy and water less efficiently and require more land per household inhabitant. Research in Norway has shown that energy use per capita is highest in single person households.[23] Therefore, it evidently becomes important that the benchmarked increase in performance more than outweighs the projected increase in households.

Embassy in London, Norwegian Building Research Institute, and the Swedish National Board of Housing.

[21] The cause of the increase is attributed to an increase in smaller households due to the combined factors of the young marrying and cohabiting later, increases in divorce, and the elderly living longer, as well as population increase.

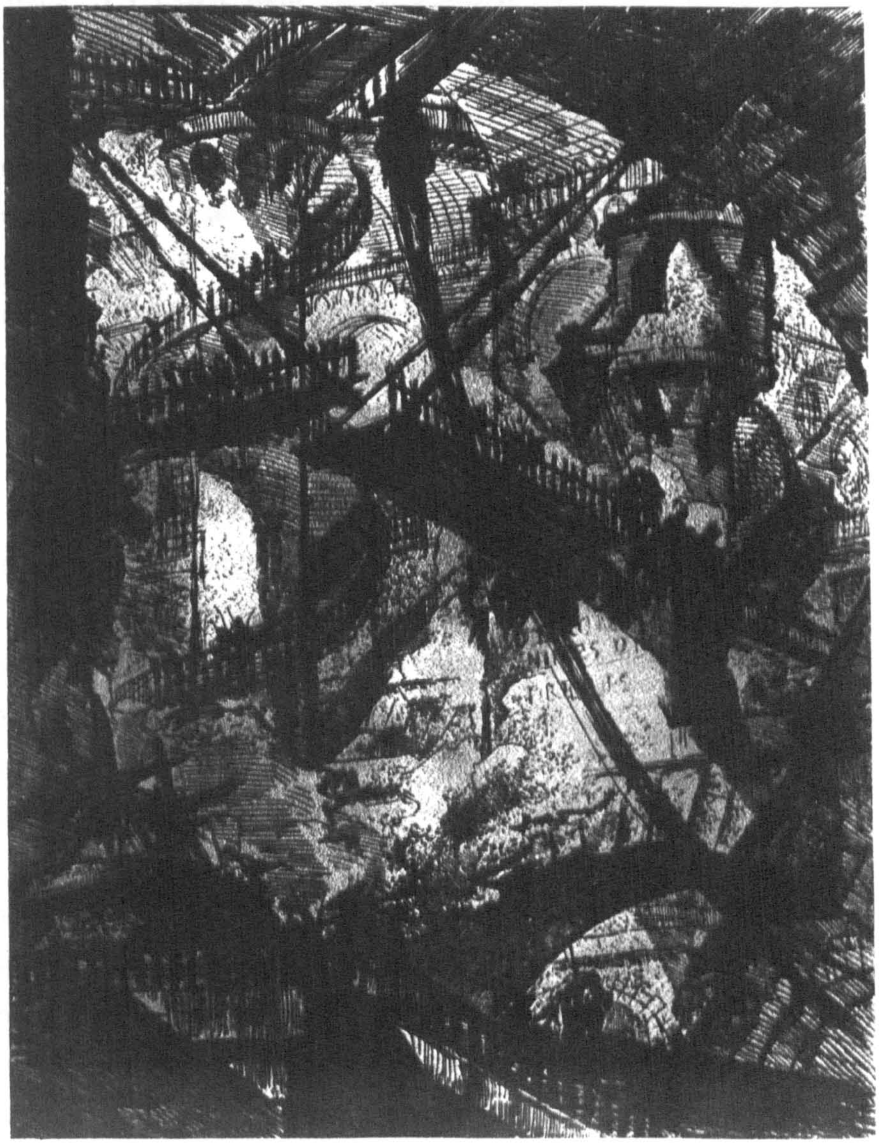
[22] Department of the Environment, Transport and the Regions. *Our Towns and Cities: The Future – Delivering an Urban Renaissance.*

The 'urban house in paradise' criteria and benchmarks proposed can be used as performance targets throughout the design process. Even in very early feasibility or conceptual design stages, the both the criteria and benchmarks can be used to establish targets that are to be achieved, and therefore inform the decision making process during the subsequent stages of the dwelling's development, in both the design and construction stages. They constitute something to measure the evolution of the dwelling against, and to ensure that decisions are made with achieving the benchmarks in mind. The assessment tool itself will assist in fulfilling the process of benchmarking, as identified in contemporary management practice,[24] by providing the framework to determine how methods and practices can be used to close the gap between the current performance standards being achieved and those of the 'urban house in paradise'.

As the benchmarks that define the standard of the performance for the criteria have been derived from a multitude of sources, two case studies have been made that demonstrate a level of performance comparable to that of the 'urban house in paradise' for a number of the criteria; these are dwellings that demonstrate best practice in a European context. This ensures that a standard of performance is not being proposed which is beyond the realm of technical feasibility.

[23] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. *Europe's Environment - The Dobris Assessment*, European Environment Agency, Copenhagen: The European Environment Agency, 1995.
[24] Zairi, Mohamed. Op. Cit.

Chapter 5



Case Studies of Examples of the Benchmark Values

5.0 Case Studies of Examples of the Benchmark Values

In the previous chapter the criteria of the 'urban house in paradise were benchmarked, concluding with a table of proposed values. It would be worthwhile setting these against case studies of dwellings that demonstrate best practice in a northern European context. This ensures that the theoretical benchmarks proposed can be achieved in reality, at least in part, and are not beyond the realm of technical feasibility; therefore that the values, derived from different sources, are not mutually exclusive.

The purpose of this section of the thesis is to propose and examine precedents that demonstrate a level of performance comparable to the benchmarks of the 'urban house in paradise', for at least some of the criteria. This will serve to clarify that whilst innovative, because these examples embody and advance best practice, in each case a proportion of the benchmarks can be achieved or are approachable. The challenge of the drawn studies that follow the creation of the matrix of benchmarks and their assessment tool will be to determine that all of these benchmarks are attainable collectively.

The dwellings in each case study, Dr Susan Roaf's house in Oxfordshire and Robert and Brenda Vale's house in Southwell, were chosen as they represent the leading edge of best practice in ultra low energy dwellings in the United Kingdom in different respects.[1] It should not be thought that because these dwellings demonstrate that some of the proposed benchmarks of the 'urban house in paradise' have been achieved, that the benchmarks do not therefore represent significant progress in best practice in the house building industry. Achieving any of the benchmarks will require significant advances, and in particular achieving them holistically.

5.1 The Oxford Solar House

The Oxford Solar House demonstrates that it is feasible to create a dwelling that generates at least an equal quantity of energy as it consumes, and therefore to produce zero net CO_2 emissions. Whilst the energy consumption during inhabitation

[1] It was intended to use a European dwelling from outside the United Kingdom as one of the case studies; however, due to a lack of sufficiently detailed information to permit analysis of the performance against a number of the criteria, this desire could not be fulfilled.

is comparable with the benchmarked value, the thermal performance is lower. The predicted design life span is greater than the benchmarked value.

Designed by the occupier, Dr Susan Roaf[2] and David Woods Architects, the Oxford Solar House is a detached dwelling situated in a suburb north of Oxford. Its 260 m² floor area is distributed across two and a half storeys in a compact, virtually square, plan form. Conceived as a demonstration of current photovoltaic technology, it is the first dwelling in the United Kingdom to be created with a photovoltaic array integrated into its structure. The 4 kW array, installed in 1995, served as a demonstration project as part of the New and Renewable Energy Programme, managed by The Energy Technology Support Unit on behalf of the Department of Trade and Industry.

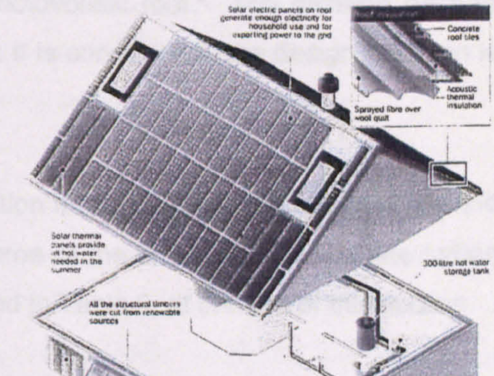


Figure 7: The Oxford Solar House

[2] Dr Roaf is a senior lecturer in architecture at Oxford Brookes University.

The key principles that underpin the design are: high levels of insulation, high thermal mass, direct gain passive solar heating, maximising natural lighting, high air tightness, and energy efficient lighting and appliances.[3] Wherever possible materials are from renewable sources, or at least with a low environmental impact in production and transportation, and to be non-toxic, low allergenic and recyclable wherever possible.[4] A conservatory on the south face preheats air drawn in through passive stack ventilation to reduce ventilation heat loss, which can be a significant factor in low energy design. In addition to the photovoltaic array, solar water heating panels are integrated into the roof; these reduce the energy demand for water heating. Space heating, and additional water heating as required, is provided from a gas-fired condensing boiler and radiators; a ceramic wood stove on the ground floor provides a secondary heat source.[5] The cost of the dwelling was £200,000, or 858 £.m^{-2}; it is estimated that if built conventionally the cost would have been 686 £.m^{-2}. Included within the additional amount is £25,000 for the integrated photovoltaic roof.[6] The dwelling aims to maximise the efficiency of the materials from which it is constructed; the design life span is 200 years.[7]

Through literature review and personal communication it has been possible to evaluate the performance of the Oxford Solar House against some of the criteria that define the 'urban house in paradise'.[8] The performance is summarised in Table 3, at the end of this section.

Of the quoted 12.6 kWh.m^{-2}.a^{-1} consumed by the dwelling, space and water heating consume 10.7 kWh.m^{-2}.a^{-1};[9] this is consumed by a condensing gas boiler working in conjunction with a solar water panel. Based on monitored data, the photovoltaic roof produces 3,093 kWh.a^{-1}, which equates to 13.3 kWh.m^{-2}.a^{-1}.[10] During the summer the energy surplus, which is exported to the utility supplier, is approximately 12 kWh per day; as

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[3] Built in masonry construction, the traditional brick and 150 mm concrete block walls have a cavity filled with 150 mm fibre insulation blocks; the roof is concrete tiled, with between 200 to 250 mm sprayed fibre over wool quilt insulation. The concrete ground floor, insulated with 160 mm insulation beneath, and concrete beam and block first floor provide a significant proportion of the thermal mass; in addition to this, internal walls are constructed from 150 mm concrete block.
[4] Lesniewski, J. and D. Thorpe. *Future Homes*, Machynlleth: Centre for Alternative Technology Publications, 1997.
[5] BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, London: HMSO, February 1996.
[6] Lesniewski, J. and D. Thorpe. Op. Cit.
[7] Ibid.
[8] The sources for this analysis were literature review and personal communication with Dr Roaf.
[9] 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.
[10] Ibid.

this is greater than the energy deficit in winter the dwelling is a net energy generator.[11] The quoted energy consumption benchmark does not explicitly state what is included in the figure, which is very low, allowing only 1.9 $kWh.m^{-2}.a^{-1}$, or 494 $kWh.a^{-1}$, for pumps, fans, lighting, appliances and cooking. Therefore it would be prudent to assume that this value accounts for only pumps and fans in addition to the space and water heating, which the benchmark analysis demonstrates as being in the region of 494 $kWh.a^{-1}$, and can be considered as part of the heating system.

The Oxford Solar House demonstrates that it is feasible to create a dwelling that generates at least an equal quantity of energy as it consumes, and therefore to produce zero net CO_2 emissions. However at the scale of generation available a critical factor in achieving this balance is minimising demand from space and water heating and household loads. For example, the ultra low energy fridge consumes only a fifth of a conventional model, and has no freezer. It was estimated that including a freezer in the dwelling would have doubled the loads in the kitchen, the total consumption of which was measured at 913 $kWh.a^{-1}$.

The proposed design life span is longer than the benchmark of the 'urban house in paradise'. However, no elaboration that substantiates why the value of 200 years is given can be determined; it is therefore difficult to determine any specific measures, such as material selection or construction detailing, that have been taken in the design or construction of the dwelling to ensure that the benchmark is achieved. This value is also significantly in excess of the mean life expectancy of all the building materials in the Research Steering Group of the Building Surveyors Division and the Building Research Establishment's *Life Expectancies of Building Components.*[12]

The literature review has not been able to determine the designed occupancy level of the Oxford Solar House. However, in the knowledge that it has five bedrooms a value can be speculated upon. If there are six inhabitants the space standards for area and volume will be 38.8 $m^2.p^{-1}$ and 78.0 $m^3.p^{-1}$ respectively; whereas if there are seven they will be 33.3 $m^2.p^{-1}$ and 66.9 $m^3.p^{-1}$; at the maximum level of ten they will be 23.3 $m^2.p^{-1}$ and 46.8 $m^3.p^{-1}$. In each of these scenarios the space standard for area is higher than that of the 'urban house in paradise'; with the exception of the latter, the space standard for volume of each is

[11] Ibid.

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

also higher. However, this does not imply that the benchmarks of the 'urban house in paradise' should necessarily be increased to match those of the Oxford Solar House; other factors should also be considered in terms of the impact in doing so. For example, increasing the size of the dwelling will require more resources in terms of materials; it may have a detrimental impact upon achieving the benchmark for density; it may also increase the overall cost of the dwelling, reducing its affordability.

If the 12.6 $kWh.m^{-2}.a^{-1}$ accounts for all of the dwelling's energy consumption, then it is an improvement on the benchmark of Energy Consumption: Inhabitation. The 10.7 $kWh.m^{-2}.a^{-1}$ consumption for space and water heating is very comparable to that proposed for the 'urban house in paradise', further implying that the 12.6 $kWh.m^{-2}.a^{-1}$ does not account for the full energy consumption. In addition, as the dwelling is larger, this could mean that the energy consumption appears lower than if the floor area were smaller, as the total energy consumption is divided by the floor area to determine the benchmark.

Despite the low energy consumption for space and water heating, which is very comparable, the thermal performance of the fabric of the Oxford Solar House is not as high as the benchmarks of the 'urban house in paradise' for all of the elements from which the envelope of the dwelling is composed. Of particular note is the difference in the performance of the roof and walls; the U-values for the Oxford Solar House are 0.14 and 0.22 $W.m^{-2}.K^{-1}$ respectively, whilst the benchmarks of the 'urban house in paradise' are almost half those values, at 0.08 and 0.12 $W.m^{-2}.K^{-1}$.[13] This might imply that the benchmarks for thermal performance do not need to be achieved in order to meet the benchmark for energy consumption of the space and water heating. However the relationship between thermal performance and energy consumption is not as direct as that might imply as other factors, such as the air tightness of the envelope, will also have an influence.

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[13] For comparison, the values for the ground floor are 0.19 and 0.13 $W.m^{-2}.K^{-1}$, and windows are 1.3 and 0.8 $W.m^{-2}.K^{-1}$, for the Oxford Solar House and 'urban house in paradise' respectively.

Criteria		Benchmarks
		Oxford Solar House
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		-1.2
CO2 emissions: On Site Construction Processes: kgCO2.m-2		-
Carbon intensity: kg.kWh-1		0.24
Construction period: weeks per dwelling		-
Contextual significance of site: Qualitative		-
Deconstruction and demolition: Recycling materials: Percent		-
Design life span: Years		200
Density:	quantitative: p.ha-1	-
	qualitative	-
Diveristy: programmes.ha-1		1
Domestic waste:	refuse: kg.p-1.wk-1	-
	recycled: kg.p-1.wk-1	-
Ecological significance of the site: Percent and qualitative		-
Ecological weight: embodied energy: kWh.m-2		-
Ecological weight: CO2 emissions: kgCO2.m-2		-
Energy consumption: construction: kWh.m-2		-
Energy consumption: inhabitation: kWh.m-2.a-1		12.6
Energy generation: kWh.m-2.a-1		13.3
Green space: Percent		-
Lifecycle cost:	Construction: £.m-2	858
	Energy: £.m-2.a-1	-
	Water: £.p-1.a-1	-
Nitrogen oxide emissions: mg.kWh-1		-
Other ecological impacts of materials: Qualitative, g.kWh-1		-
Other greenhouse gas emissions: g.kg-1		-
Pollution: energy consumption inhabitation: g.kWh-1		-
Procurement strategy: Qualitative		-
Quality of internal environment:	indoor pollution: Qualitative	-
	daylight: living, kitchen, beds: Percent	-
	ventilation: ac.h-1	0.5
	airtightness: ac.h-1 at 50 Pa	-
Recycling construction waste: Percent		-
Adaptability: Internal loadbearing walls: Internal walls		1
Space standards: Area	1 person: m2.p-1	-
	2 persons: m2.p-1	-
	3 persons: m2.p-1	-
	4 persons: m2.p-1	-
	5 persons: m2.p-1	-
	6 persons: m2.p-1	38.8
	7 persons: m2.p-1	33.3
	8 persons: m2.p-1	-
	9 persons: m2.p-1	-
	10 persons: m2.p-1	-
Space standards: Volume	1 person: m3.p-1	-
	2 persons: m3.p-1	-
	3 persons: m3.p-1	-
	4 persons: m3.p-1	-
	5 persons: m3.p-1	-
	6 persons: m3.p-1	78.0
	7 persons: m3.p-1	66.9
	8 persons: m3.p-1	-
	9 persons: m3.p-1	-
	10 persons: m3.p-1	-
Thermal Performance:	Roof: W.m-2.K-1	0.14
	Exposed walls: W.m-2.K-1	0.22
	Ground and exposed floors: W.m-2.K-1	0.19
	Windows and rooflights: W.m-2.K-1	1.3
	Opaque outer doors: W.m-2.K-1	-
Use of recycled materials: Percent		-
Use of renewable raw materials: Percent		-
Utilisation of local resources: km		-
Water consumption: construction: l.m-2		-
Water consumption: inhabitation:	potable: l.p-1.d-1	-
	rain and grey: l.p-1.d-1	-
	total: l.p-1.d-1	-

Table 3: Performance benchmarks of the Oxford Solar House

5.2 The Vale House, Southwell

The dwelling was designed on the principle of autonomy. For example, through a large roof area for collection and rainwater storage the dwelling is independent of a mains water supply. Although designed to have an airtight construction, the predicted value is above that of the benchmark; despite this the energy consumption during inhabitation is comparable to the benchmark, and can virtually be fulfilled through renewable sources. With a large site the dwelling falls substantially short of the density benchmark.

The principal philosophy used by the architects Robert and Brenda Vale, in respect to sustainability, in the design of their dwelling is autonomy in all services; the only utility supplies are electricity and telephone. In many respects it is the manifestation of thirty years of research by the Vales, the original mark of which was the publication of *The Autonomous House – Design and Planning for Self-Sufficiency* in 1975.[14] The Vales have attempted to create a dwelling that, as far as possible, can be serviced through the natural resources that fall upon its site.

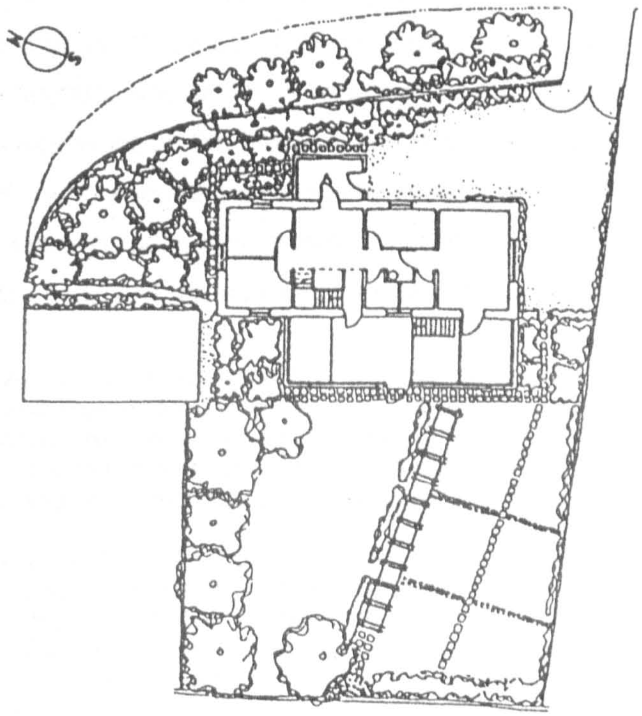

Figure 8: Site plan of the Vale's dwelling, Southwell

[14] Vale, Brenda and Robert. *The Autonomous House – Design and Planning for Self-Sufficiency*, London: Thames and Hudson, 1975.

Designed for a family of five, the two and a half storey detached dwelling was built using relatively traditional technologies.[15] The philosophy of achieving airtight construction, which is seen by the Vales as fundamental in low-energy dwellings, is that it is created by construction detailing. For example, the use of concrete floors reduces the possibility of differential thermal movement that might occur between timber and concrete; and also the possibility of shrinkage in a timber floor. Both would open cracks where air could enter the dwelling.[16] Other strategies to achieve an airtight shell were design led, such as having a draught lobby to both external doors. Mechanical ventilation with heat recovery services the kitchen and bathrooms, with the incoming air being preheated by the conservatory on the west elevation. The procurement route was also traditional, with competitive tendering used to select a contractor on the basis of cost.[17]

As opposed to being integrated with the structure of the dwelling, as at the Oxford Solar House, a photovoltaic array is placed on a pergola in the rear garden. The 2.2 kW array is composed of 36 panels, which are connected to the national electricity grid through an inverter. 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 new. Other implications included higher costs, and the additional space required to store

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[15] Brick and dense concrete block walls have 250 mm of insulation in a fully filled cavity. The clay pantile roof is insulated with 500 mm of cellulose fibre, underlined with an exposed softwood structural decking in order that the habitable space extends into the roof void to maximise use of the enclosed space. Ground and first floors are both constructed from concrete beam and blocks to add to the thermal mass, which is increased further by dividing the rectangular plan into bays with load-bearing concrete block crosswalls.

[16] Further detailing to ensure airtight construction includes the roof being underlined with a reinforced polyethylene air and vapour barrier, which is carefully detailed to meet the wet plaster on the walls to achieve a seal. The plaster on the walls was brought right down to meet the screed on the concrete block floors. Wet construction is seen as advantages in airtight construction. Placing insulation in the plane of the roof meant that there were few penetrations through the air and vapour barrier. Window and door openings are carefully sealed. This was achieved in three stages: windows and doors with in-built seals around opening components were specified; these were fitted into plywood wall boxes, and a CFC-free expanding foam used to put a compressible airtight seal around the inner edge of each frame, between the frame and plywood box; finally the boxes themselves were sealed to the internal face of the inner leaf with silicone seal prior to the walls being plastered. BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, London: HMSO, February 1996.

[17] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*,

the batteries, which can pose hazards such as fire and explosion.[18] The only other energy source in the dwelling is a small wood stove; the primary source of space heating is incidental gains from the occupants and appliances, and passive solar gains from the windows and conservatory.

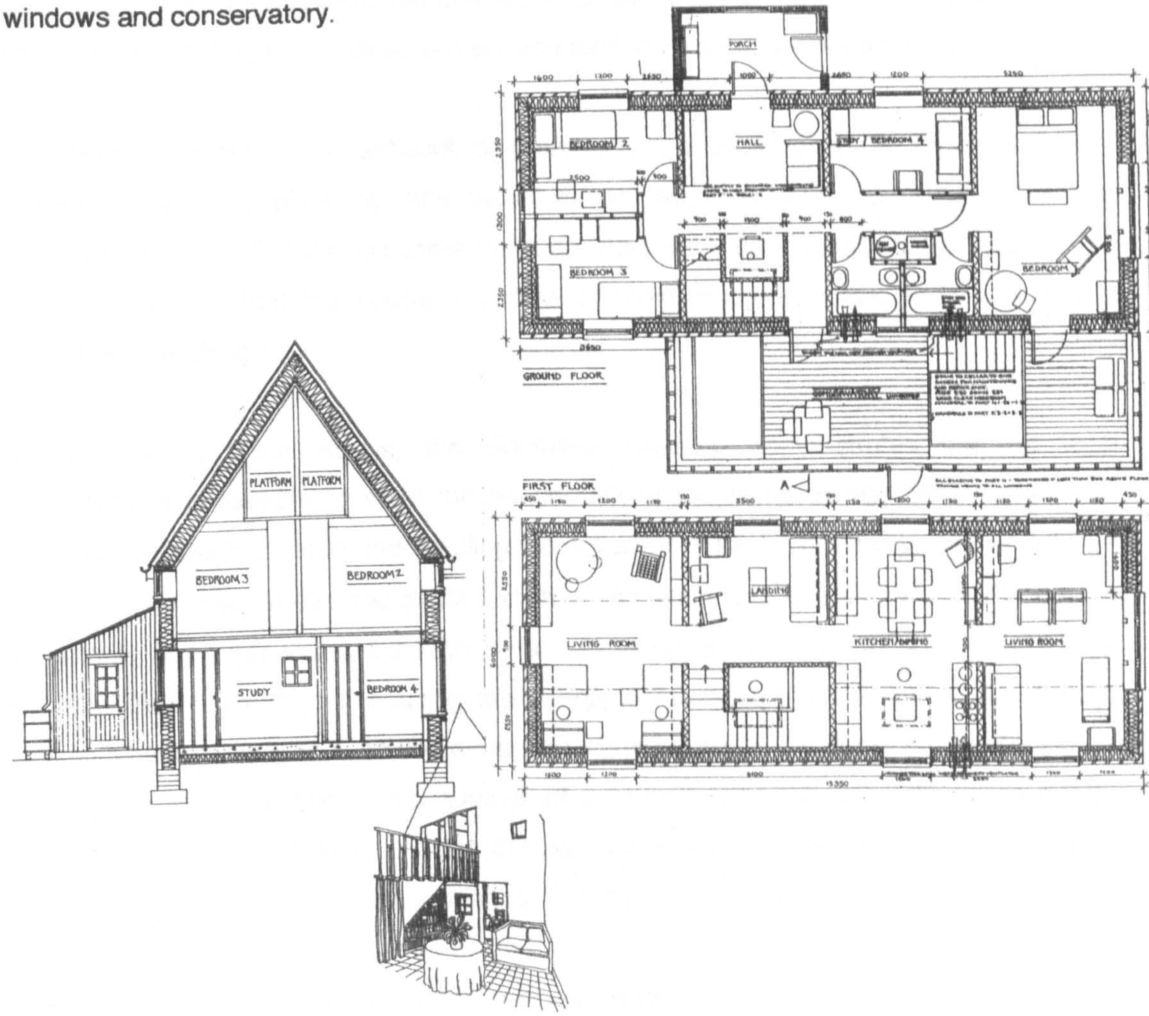

Figure 9: Plans and section of the Vale's dwelling, Southwell

A basement has been included under the whole ground floor to accommodate 30,000 litres of rainwater storage, which provides all of the dwelling's water supply; rainwater is collected from the dwelling and conservatory roofs. This also provides space to accommodate a domestic sewage composter. In order that the limited surface area for collection and relatively low rainfall on the site can fulfil all of the dwelling's water needs, consumption had to be reduced from that of the typical dwelling. The 51 litres per person per day used on

London: Thames & Hudson Limited, 2000.
[18] Ibid.

average for flushing the toilet was an obvious target.

Literature review has also been able to determine the performance of the Southwell dwelling against a number of the criteria that define the 'urban house in paradise'. The performance of the dwelling is discussed below, and summarised in Table 4, at the end of this section.

It has been commented that, although different to typical dwellings in the United Kingdom, "... particularly in the plumbing, [the Vales] do not seem to have made the house less convenient to live in."[19] Although some might consider the Vale's lifestyle to be "spartan",[20] it was their intention that the house might be different, but not worse, to live in than a conventional dwelling.[21]

Like the Oxford Solar House, 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.[22] However, also like the OSH, this demanded a significant reduction in the energy demands made by space and water heating, lighting and appliances.

It might be considered that using the national electricity grid to, in effect, store excess generation compromises the autonomous philosophy of the dwelling. However, it is justified through the reduction in resource consumption over using other storage methods such as batteries. Provided that the generation at least equals consumption, the dwelling might be considered to produce no CO_2 during inhabitation. Furthermore, if net annual generation exceeds consumption, the dwelling would contribute to reducing the emissions arising as a consequence of others, by providing a renewable energy source to the grid.

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19 BRECSU. 'Review of Ultra-Low-Energy Homes - Ten UK Profiles in Detail,' *General Information Report 39*, London: HMSO, March 1996, p. 26.
20 Voelcker, Adam. 'Vale of Health', review of *The New Autonomous House – Design and Planning for Sustainability*, by Robert and Brenda Vale, in *The Architectural Review*, Number 1241, July 2000.
21 Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability.*
22 Ibid.

The Southwell house demonstrates that it is possible to achieve zero potable water consumption, and a household rainwater consumption of 170 litres per day, or a consumption per inhabitant of 34 litres per person per day. This was lower than predicted by the Vales, and is an advance on the proposed benchmark value for water consumption. However, achieving this has required the utilisation of specific servicing, such as composting toilets and showers with flow restrictors. Furthermore, it has also required a lifestyle approach that respects the finite supply of the resource, which includes limiting the time an individual spends in the shower. This could be viewed positively, through raising awareness that water is not a limitless resource; however it may also pose problems to be overcome in the wider application of such servicing, in terms of acceptability in people not as environmentally sensitive as the Vale household. The decision to use filtered rainwater for all functions, including drinking and cooking, to make the dwelling autonomous from the utility supplier, with no potable mains water consumption, may also prove contentious in wider application.

Although conscious efforts were made to use materials from local sources, no detailed embodied energy analysis of the dwelling has been undertaken; although it is recognised that such a study is proposed. This is a significant issue, as the dwelling uses a high thermal mass, 0.22 $kWh.K.m^{-2}$, to minimise energy consumption during inhabitation, which will lead to a higher embodied energy for the dwelling. Therefore, the embodied energy becomes more relevant in terms of the lifecycle energy consumption of the dwelling. If the thermal mass, contributes to reducing the energy consumption during inhabitation, this might mitigate the additional embodied energy required to achieve it. However, the relationship becomes more complex if the additional resource extraction and depletion is also taken into account; a very low-mass dwelling could have been constructed in timber frame, using a renewable source.

The 'drying out' of the wet construction used, in part, to lower the infiltration rate, caused problems during the first year of occupation. Condensation was observed forming over the glazing, window surrounds and in the corners of the concrete floors where air circulation is poor; mould growth was noticed at the edges of roof lights.[23] Ironically, this is as a consequence of the airtight construction of the dwelling, which wet trades were used to help

[23] BRECSU. 'Review of Ultra-Low-Energy Homes - Ten UK Profiles in Detail,' *General Information Report 39.*

create. This might suggest that if an airtight structure can be achieved with minimal use of wet trades, the likelihood of condensation occurring upon occupation would be reduced.

The residential density of the house is very low. Designed for five people on a large, 575 m^2 site, the net residential density is 86 people per hectare; a typical greenfield housing estate built by a national house builder might approach 100 people per hectare.[24] This could be considered an inefficient use of land, which is a natural resource. To some extent it would be difficult to have increased the density of the site; the decision to locate the photovoltaic array in the garden increased the need for open space, and the site is bounded by other properties on all but one side making the inclusion of another dwelling on the site problematic. However, for a dwelling that demonstrates many facets of ecological sustainable living, it is unfortunate that efficiency of land use was not among them.

Both the generic criteria and a series of benchmarks for each of those criteria that collectively define the performance of the 'urban house in paradise' have now been established, and demonstrated as critically relevant and innovative. For an architect to compare the performance of a design for a dwelling against those benchmarks a methodology, or tool, for assessment must be developed; this should be sufficiently robust so as to provide a consistent evaluation process. Prior to the design of the assessment methodology itself, two precursory studies had to be conducted. Prioritising established a hierarchy between the criteria, on the basis of which will contribute most to improving the overall sustainability of the dwelling. Identifying the interrelated links between the criteria provided the structure from which to design the assessment, ensuring that it responds to the consequential impacts of the criteria upon each other.

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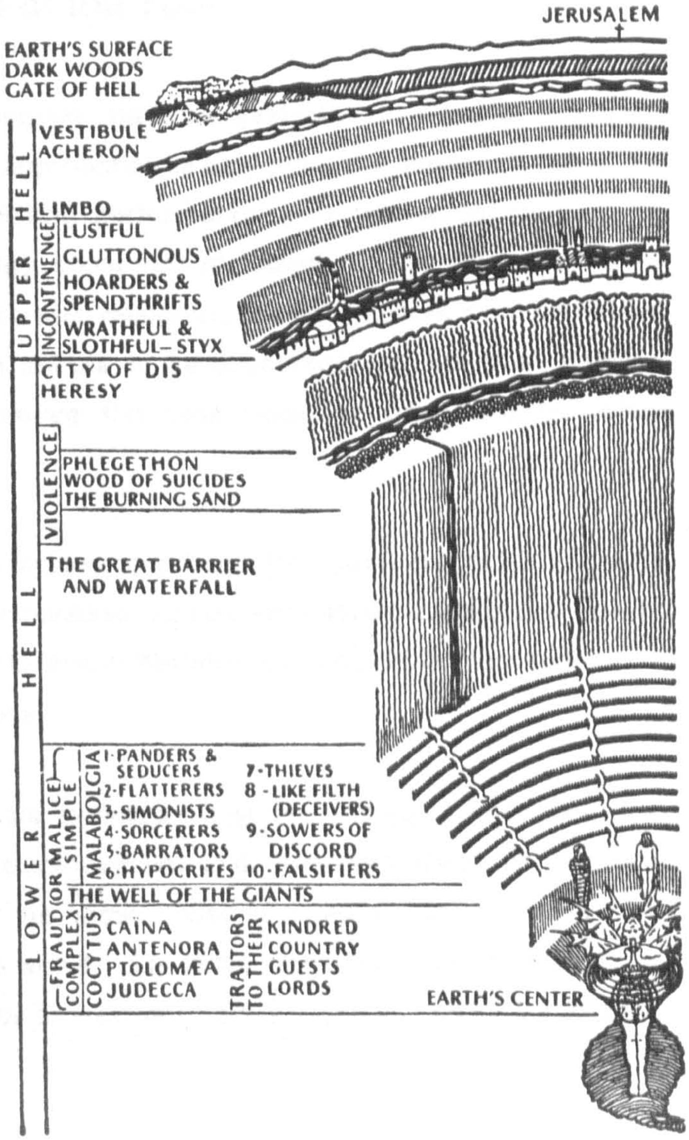
[24] Fulford, Charles. 'The Compact City and the Market' in Jenks, Mike, Elizabeth Burton and Katie Williams. *The Compact City – A Sustainable Urban Form?*, London: E & F N Spon, 1996.

Criteria		Benchmarks
		Vale House, Southwell
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		5.2
CO2 emissions: On Site Construction Processes: kgCO2.m-2		-
Carbon intensity: kg.kWh-1		-
Construction period: weeks per dwelling		-
Contextual significance of site: Qualitative		Yes
Deconstruction and demolition: Recycling materials: Percent		-
Design life span: Years		-
Density:	quantitative: p.ha-1	86
	qualitative	No and Yes
Diveristy: programmes.ha-1		1
Domestic waste:	refuse: kg.p-1.wk-1	-
	recycled: kg.p-1.wk-1	-
Ecological significance of the site: Percent and qualitative		0, No and No
Ecological weight: embodied energy: kWh.m-2		-
Ecological weight: CO2 emissions: kgCO2.m-2		-
Energy consumption: construction: kWh.m-2		-
Energy consumption: inhabitation: kWh.m-2.a-1		22.9
Energy generation: kWh.m-2.a-1		9.2
Green space: Percent		290
Lifecycle cost:	Construction: £.m-2	823.86
	Energy: £.m-2.a-1	-
	Water: £.p-1.a-1	-
Nitrogen oxide emissions: mg.kWh-1		-
Other ecological impacts of materials: Qualitative, g.kWh-1		-
Other greenhouse gas emissions: g.kg-1		0
Pollution: energy consumption inhabitation: g.kWh-1		-
Procurement strategy: Qualitative		Lump sum competitive tender
Quality of internal environment:	indoor pollution: Qualitative	-
	daylight: living, kitchen, beds: Percent	-
	ventilation: ac.h-1	0.2
	airtightness: ac.h-1 at 50 Pa	2
Recycling construction waste: Percent		-
Adaptability: Internal loadbearing walls: Internal walls		0.81
Space standards: Area	1 person: m2.p-1	-
	2 persons: m2.p-1	-
	3 persons: m2.p-1	-
	4 persons: m2.p-1	-
	5 persons: m2.p-1	33.8
	6 persons: m2.p-1	-
	7 persons: m2.p-1	-
	8 persons: m2.p-1	-
	9 persons: m2.p-1	-
	10 persons: m2.p-1	-
Space standards: Volume	1 person: m3.p-1	-
	2 persons: m3.p-1	-
	3 persons: m3.p-1	-
	4 persons: m3.p-1	-
	5 persons: m3.p-1	86.1
	6 persons: m3.p-1	-
	7 persons: m3.p-1	-
	8 persons: m3.p-1	-
	9 persons: m3.p-1	-
	10 persons: m3.p-1	-
Thermal Performance:	Roof: W.m-2.K-1	0.065
	Exposed walls: W.m-2.K-1	0.14
	Ground and exposed floors: W.m-2.K-1	0.2
	Windows and rooflights: W.m-2.K-1	1.1
	Opaque outer doors: W.m-2.K-1	0.55
Use of recycled materials: Percent		-
Use of renewable raw materials: Percent		-
Utilisation of local resources: km		-
Water consumption: construction: l.m-2		-
Water consumption: inhabitation:	potable: l.p-1.d-1	0
	rain and grey: l.p-1.d-1	34
	total: l.p-1.d-1	34

Table 4: Performance benchmarks of the Vale's dwelling, Southwell

Chapter 6



Comparative Models of the Tool

6.0 Comparative Models of the Tool

The existing environmental assessment methods evaluated in Chapter 2.0 were reconsidered, this time in terms of approaches to designing the assessment tool for the 'urban house in paradise'. Rating performance as a score, as opposed to dimensioned values such as energy consumption, could reduce the incentive to improve performance. In terms of format, designing the assessment as a worksheet enables interrelationships between criteria to be accounted for; however, using a computer as an interface can reduce the time taken to undertake an initial assessment.

Before developing the methodology for assessing a design for a dwelling against the criteria and benchmarks of the 'urban house in paradise', some comparative models of assessment techniques were studied. This served to ensure that when evolving the tool, advances were made upon current assessment methods.

Some of the performance assessment techniques that are already in existence, and evaluated in Chapter 2.0, can provide clues as to how to develop the tool that will be used to assess the matrix of benchmarks of the 'urban house in paradise', both in terms of its structure and how the user interfaces with it. Due to the lack of interrelation between the criteria in first generation environmental assessment models, comparatives for the structure of the tool are also sought elsewhere.

The use of the Standard Assessment Procedure (SAP) or the Building Research Establishment Domestic Energy Model (BREDEM) as the methodology for assessing the energy consumption of the dwelling is discussed under the Energy Consumption: Inhabitation criterion in Annexe 3.16, refer to Volume 3. What is relevant for these in terms of the working structure of the tool is that they have to take account of a number of factors, each of which are interrelated in terms of determining the overall energy consumption of the dwelling. For example, the air tightness of the structure, the level of thermal insulation and the passive generation through glazing all have a quantitative consequential effect on the overall energy consumption.

Both the SAP and BREDEM calculations have versions that use a worksheet process to determine final energy consumption value;[1] BREDEM has now superseded this with a computer software version.[2] The worksheet takes the form of a series of numbered steps in which information regarding the dwelling is entered, or calculations undertaken. The worksheets suggest a method of how to structure the algorithms that account for the quantified interrelationships between the criteria of the matrix, to determine their relative impacts. However, the SAP and BREDEM models only offer a start point; it is possible that these could be developed into the wider assessment of other environmental impacts or performance criteria, in addition to energy consumption. From there, a computer model could also be generated from the framework of the worksheet.

Discussion with Dr Brian Anderson of BRECSU at the Building Research Establishment, who are responsible for the continued development of the SAP assessment, revealed areas which they consider could potentially be improved upon.[3] The hot water energy requirement is based on the floor area of the dwelling; the values, in tabulated form, are based on measured consumption from a range of dwelling sizes, and the table is derived by interpolating between the measured values; these values are now somewhat out of date. A significant improvement would be to update the table, or base the energy requirement on the predicted water consumption of the dwelling. The latter method would allow account to be made for low consumption appliances and fittings, such as low flow showerheads or flow restrictors. The SAP assessment, whilst taking account of the incidental heat gains from lighting, appliances, cooking and metabolic gains from the inhabitants, does not take account of the energy consumed by the first three of these, although the BREEDEM assessment does. However, both make their gains and consumption values on the basis of the floor area of the dwelling, as for the energy requirement for water heating. The shortcoming of this method is that it does not allow account to be made for low consumption appliances, with resulting lower incidental gains. Creating the methodology for amending these shortcomings will create a highly relevant and significant advance on the existing SAP assessment.

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[1] Department of the Environment, Transport and the Regions. The Government's Standard Assessment Procedure for Energy Rating of Dwellings, London: HMSO, 1998; and Anderson, B. R. 'Energy Assessment for Dwellings using BREDEM Worksheets', *IP13/88*, Building Research Establishment, November 1988.

[2] L. D. Shorrock and B. R. Anderson. 'A Guide to the Development of BREDEM', *IP 4/95*, Building Research Establishment, February 1995.

The Dutch assessment model *Eco-Quantum* provides a comparison for the connected approach to embodied and lifecycle impacts that is envisaged to the tool. However it lacks a truly interrelated structure as the assessment uses three different analysis models, including one for lifecycle impacts of materials and another for the energy modelling, rather than combining them into one assessment method. Such a combination would allow direct comparisons to be made between the effects of changing materials specification, such as increasing insulation thickness or changing the construction technology, on the embodied energy and lifecycle energy consumption. This is evidently an approach the 'urban house in paradise' tool should adopt. Another shortcoming of *Eco-Quantum* is that the environmental impact of materials is based on a series of assumed standard construction methods, therefore the potential for determining the impact if diverging from the standard assumptions is limited. Furthermore, in terms of the analysis of the dwelling's performance, the assessment does not identify the difference between embodied energy consumption and energy consumed during the occupation period; achieving an optimum balance between these two, in the context of the dwelling's predicted life span, will be one of the principal ways in which to identify the most sustainable balance between embodied and lifecycle inputs.

Eco-Quantum is purely a tool to assess relative environmental impact; the output profile is given in terms of scores against a number of environmental effects, such as raw material depletion, ecotoxicity, and waste.[4] It does not assess the performance in terms of quantitative benchmarks, such as energy consumption in terms of $kWh.m^{-2}.a^{-1}$. Scoring in terms of relative environmental impact gives little incentive, over creating more environmentally sensitive buildings, to improve upon 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. Even in terms of housing, where the client or house builder is unlikely to be the occupier, there could be benefit through marketing the reduced annual costs in a particular dwelling.

The *Green Builder Programme*, described in more detail under Annexe 1.0, is one of the few environmental assessment models that acknowledges and incorporates the notion of linkages between criteria. This is in the sense that it contains a specific category entitled

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[3] Personal communication, Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.

Integration, under which a system or resource option is awarded credit for its ability to undertake several functions.[5] For example, points would be assigned to a grey water system that both removes water from the waste water system and uses it for irrigation. However, this methodology of accounting for interrelated criteria is based on an award that is feature specific, simply assigning points at a specific stage in the assessment for integrated criteria; it does not measure the quantitative consequential effects between criteria, such as the quantity of water required for irrigation, and the fraction of that provided by the waste water system, and therefore could not be used to determine the most sustainable balance between the performance of different criteria.

Envest, whilst being an assessment model for office buildings, demonstrates two potentially valuable lessons for the design of an assessment tool for dwellings. Firstly, it provides an embodied energy calculation of the building, one of the first environmental assessment models to do this; however the assessment is particularised to office buildings.[6] Also, the methodology used, like *Eco-Quantum*, bases the assessment on the quantity of materials typically in one square metre of the construction type selected. Therefore the assessment is made on the basis of typical construction technologies, and applying that value to the area of each element of the building's envelope, and not on the actual quantity of material in the particular building. The latter method would be capable of being more specifically tailored to a particular construction method being used, and therefore provide a more accurate evaluation of the energy embodied in that fabric. This provides a potentially significant advance for an assessment tool that quantifies the embodied energy of a building on the actual quantity of materials used to construct it, than basing the assessment on typical values.

Envest is also relevant as a comparative model in terms of its interface with the individual conducting an assessment, being designed in the form of a piece of computer software. Initially basic data is entered into the computer, to define the area, shape and height of the building. The programme minimises the time taken to undertake an initial, broad-brush assessment by using default values, which assume typical performance values on the basis of minimum regulatory standards. The default values can subsequently be updated to provide a more detailed analysis. However, in many situations the specification for a

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[4] IVAM website, 22 August 2000: www.ivambv.uva.nl/IVAM/therma_d/EQ-paper.html
[5] Cole, Raymond J. 'Prioritising Environmental Criteria in Building Design and Assessment', in Brandon, P. S., P. L. Lombardi and V. Bentivegna. *Evaluation of the Built Environment for Sustainability*, London: E & F N Spon, 1997.

building can only be selected from a limited number of options from an on-screen menu. This limits the versatility of the model, and restricts its accuracy; for example, only two specifications of mechanical ventilation can be selected. This inflexibility limits the accuracy of the predicted performance, in particular in respect to the energy consumption during the period of occupancy.[7] Clearly, moving from a manual worksheet to a more powerful method of analysis, such as provided by a computer, should be used as an opportunity to expand the versatility of the assessment rather than inhibit it.

GB Tool is also comparable through its format as a piece of computer software. This has enabled the designers of the assessment to fulfil their specific goal of establishing a structure that can be used at various levels of detail, from broad-brush assessments to very detailed ones. This is achieved through the format of the interface with the user, and the use of default values that can subsequently be updated. A shortcoming of *GB Tool* is that, like *Envest*, the performance of the building is measured as a dimensionless, abstract score. Each category is scored between -2 and +5,[8] this is a narrow profile through which to compare the relative performance of a range of different buildings; as the score is dimensionless comparisons can only be relative.

In conclusion, in terms of the structure of the 'urban house in paradise' assessment tool and its working methodology, the following points can be identified in the preceding analysis of comparative precedents or examples. These are issues that the design of the tool should respond to in order that it can attempt to advance current assessment methods.

The user interface and structure of the tool should maximise the potential to vary aspects of the dwelling's specification, in order create a high degree of flexibility in finding the most sustainable balance of benchmarks' performance from as wider scope of variables as desired. This should also increase the tool's versatility in being capable of assessing different dwelling types, such as detached, semi-detached and terraced house, and various types of flats.

Using default values should reduce the time taken to conduct an assessment in the first instance. Where steps within the assessment are related to regulatory standards, the

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[6] This is primarily restrictive through the limited variety of construction methods that can be selected.
[7] Interview conducted with Jane Anderson of the Building Research Establishment's Sustainable Construction Unit, 16 August 2000.

minimum acceptable value can be used as this would have to be achieved; for example, the thickness of insulation required to achieve Building Regulation compliance could be used in the thermal performance assessment. A disadvantage of using default values based on minimum regulatory standards is that they may create complacency through not encouraging the user to maximise the performance in all parameters; the profile of benchmark scores should therefore make this evident. All the default values should be capable of being overridden in order that the tool does not dictate any parameter of the dwelling's specification.

Designing the assessment methodology in the format of a worksheet enables the interrelationships between criteria to be identified, quantified and accounted for in an assessment. Subsequently this worksheet can serve as the basis through which to convert the assessment into a piece of computer software, which will facilitate incorporating the features identified above.

Having appraised the inadequacies and strengths of existing assessment methods in terms of designing the assessment tool for the 'urban house in paradise', the next stage of the research was to develop the methodology for the tool. Responding to the shortcomings identified, the first two parts of which was to identify hierarchy and then interrelation between the criteria.

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

Chapter 7

Prioritising the Criteria for the Tool

7.0 Prioritising the Criteria for the Tool

Having identified the lack of relative significance as an inadequacy of existing assessments, during this chapter a hierarchy is established for the criteria that define the 'urban house in paradise'. This is based upon the relative significance of each in terms of improving the ecological sustainability of the dwelling.

Following the determination of the benchmarks, the criteria can be prioritised on the basis of those values. Such a process has been achieved in part by others, but not in terms of a holistic set of performance criteria. The purpose of this process is to prioritise the criteria that define the 'urban house in paradise', on the basis of which will make the most significant contribution to reducing the dwelling's environmental impact. This will be determined by assessing the reduction in impact that will be achieved by adopting the proposed benchmarked standard for each criterion, as opposed to the typical standards of current new housing. The decision was taken to focus upon solely ecological sustainability to narrow the scope of the work; it is acknowledged that social and economic sustainability could be used as the basis for refining the prioritisation in future research, and a methodology is used that will facilitate that.

The purpose that this process will serve is threefold. Firstly it will give a structure to the matrix so that the criteria can be ranked hierarchically in terms of the reduction in impact made by adopting the standards of each. Secondly it will enable the assessment methodology to acknowledge improvements in the performance of one criterion to the detriment of another if the former has greater significance in reducing the overall environmental impact of the dwelling. Thirdly it will facilitate focusing the study onto the criteria that will have the greatest reduction in impact during the subsequent stages of work.

7.1 Deep Ecology as a basis for prioritisation

This section proposes using a Deep Ecological approach to sustainability, as opposed to anthropocentric, as the philosophical underpinning for the methodology of prioritising the criteria. The improvements in the ecological sustainability of the dwelling are therefore based upon the reduction in impacts upon any natural system, rather than only those with human related interest or value.

In the earlier discussion on the scope of 'paradise' within the context of the thesis, the frame of reference was defined as the ideal condition of the man-made environment in harmony with nature; reference was made to the interpretation of paradise in Eastern religion as a perfect natural environment. The paradigm of Deep Ecology made itself distinct from other contemporary ecological thought through its non-anthropocentric basis. It perceives the natural environment as a holistic interrelated system, in which the human race is at most an equal, and never superior, to other forms of life, and that all ecosystems, whether humans are affected by them or not, are of equal value. It is a philosophy, "whose values reflect an awareness of the integrity of the whole of nature."[1]

In the focus of its concern on the ecology of the planet, and in particular the preservation of wilderness territories, the Deep Ecology philosophy does not necessarily exclude the urban environment. "It is right and proper that the movement should run from wildlife to urban health. But there can be no health for humans and cities that bypass the rest of nature."[2] There is, therefore, a relationship between the perception of the natural environment in a Deep Ecology sense, and the nature of 'paradise', as an ideal condition of nature in harmony with the manmade environment. Deep Ecology is also of relevance in the context of the aim of the thesis to create a holistic matrix that demonstrates the interconnection between the criteria within it. A principle of Deep Ecology is that is perceives the world as a network of phenomena that are fundamentally interconnected and interdependent.[3]

Fritjof Capra, writing of the ethics associated with the new ecological paradigm of Deep Ecology, states that, "... the most important task for a new school of ethics will be to develop a non-anthropocentric theory of value, ..."[4] The value structure that is used to determine the priority of the criteria within the matrix could reflect the philosophy of the paradigm of Deep Ecology. This will create a preference rating which reflects the holistic, interconnected view of the natural environment, in which humans are an equal part, when considered with other species and ecosystems, rather than above or outside of nature.

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[1] Snyder, Gary. 'Culture or Crabbed,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995, p. 49. In partnership with the Deep versus Shallow question of the intrinsic value of all species for their own sake, is the question of, "... what, if any, ethical obligations humans [have] to the nature of other species." Foreman, Dave. 'The New Conservation Movement,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995, p. 52.
[2] Ibid.
[3] Capra, Fritjof. 'Deep Ecology - A New Paradigm,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995.
[4] Ibid., p. 20.

In view of the emphasis placed on the balance between the natural environment and man, and the definition of paradise as an ideal condition of nature, it is proposed that the criteria will be prioritised against their relative contribution to ecological sustainability, as understood in terms of Deep Ecology. This is an ecocentric view of ecological sustainability, as opposed to an anthropocentric one, in which the well-being of all natural systems on the earth are considered equally, as opposed to just the well-being of ones with a direct effect upon the human race. For example, an anthropocentric view of resource depletion would only be concerned with the resources that have, or are likely to have value for human use; "... if no human use is known, or seems likely ever to be found, then it does not matter if that resource is destroyed."[5] As previously identified, this is the view that would be taken by adopting the Brundtland definition of sustainable development. Deep Ecology, however, is concerned with resources and habitats for all species of life, and therefore considers the depletion of any resource as destructive.

Deep Ecology was used as an intellectual standpoint from which to undertake the prioritising of the criteria. It served as a philosophical basis from which to evaluate the relative significance of each of the criteria to improving the sustainability of the dwelling. The increase in the ecological sustainability of the dwelling proposed by the 'urban house in paradise' is informed by a Deep Ecological approach to the prioritising, by considering the reduction in impacts made by the benchmarks equally in terms of any natural system, as opposed to the value of the reduction in anthropocentric terms.

7.2 Prioritisation within existing environmental assessment methods

An evaluation of the small number of assessment methods that use prioritising within the assessment provides an insight into difficulties that have arisen in undertaking such a process in the past. These were learnt from, so that a methodology could be developed that attempted to overcome them.

Very few existing environmental assessment models use an explicit weighting system to acknowledge the relative significance of the criteria, and none in a holistic sense. In the

[5] Naess, Arne. 'The Deep Ecological Movement – Some Philosophical Aspects,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995, p. 72.

Environmental Standard assessment model, Prior and Bartlett comment on the problems of assessing issues of environmental degradation in relation to each other. They see it as problematic to relate criteria on a comparative basis due to the difficulty associated with creating a frame of reference under which every criteria can be compared with each other.

> There is insufficient information to carry out an objective weighting of environmental effects as diverse as the health of individuals, ozone depletion, global warming and the future value of resources such as fossil fuels.[6]

The only form of 'prioritising' of the criteria within the *Environmental Standard* has been to categorise them under the three classifications of 'global', 'local' and 'indoor' scales. This organises each of the criteria, depending upon the context in which the impact of the criterion will be made. In order to obtain compliance with the *Standard*, there is a mandatory mix of the three scales that has to be obtained. All of the criteria have equal significance; a weakness of this structure is that whilst two projects may have an equal score under the *Standard*, one may be contributing more to reducing its ecological impact.

Cole identifies several factors upon which attempts have been made, albeit at the expense of over-simplification, of developing a common basis for comparing and contrasting environmental impacts.[7] These include:

- *Cost*. All environmental impacts are reduced to a monetary cost value.
- *Equivalence method*. This method uses the relative environmental toxicity as a weighting factor to create a comparative index of air emissions and liquid effluents.
- *Ecological footprint*. This refers to the area of land required to biologically produce all of the resources consumed and to assimilate wastes generated, indefinitely. Therefore, each criterion is considered in terms of a value of land area.
- *Ecocost*. For this assessment, often of building materials, each of the impacts are evaluated in absolute environmental terms, such as: land degradation, toxic impact, energy use impact, transport impact, longevity and recycle/reuse of product.[8]

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[6] Prior, Josephine J. and Paul B. Bartlett. Environmental Standard - Homes for a Greener World, Garston: Building Research Establishment, 1995.

[7] Cole, Raymond J. 'Prioritising Environmental Criteria in Building Design and Assessment,' in Brandon, P. S., P. L. Lombardi and V. Bentivegna. *Evaluation of the Built Environment for Sustainability*, London: E & F N Spon, 1997.

[8] Over simplification is a potential weakness of *Ecocost* assessment, which reduces the very complex issue of ecological degradation into a number of relatively simple equations. These produce a single score between 1 and 0, where 1 represents the ecological degradation of the environment, and zero a healthy, sustainable planet.

A difficulty for prioritising the criteria of the 'urban house in paradise' is that, as it is creating a holistic model, there is a very diverse range of criteria being assessed. The common bases that Cole identifies often rely on there being a common value between the criteria. For example, the Equivalence method only considers a restricted range of criteria such air or liquid emissions arising from construction processes. Also, in terms of ecological footprint, no account can be made of the land area associated with the production of non-renewable resources. It has been commented that methodological difficulties exist in assessing lifecycles impacts in terms of their ecological footprint;[9] in order that the footprint of initial construction can be compared with that of recurring impacts over the building's life span, lifecycle considerations are a fundamental principle of the 'urban house in paradise' and its assessment.

The Canadian Building Environmental Performance Assessment Criteria (BEPAC) of new office buildings contains 75 criteria of assessment; these are structured under five 'environmental topics'.[10] BEPAC has attempted to account for the relative significance of the different environmental criteria by attributing a weighting to reflect its priority relative to other criteria within the same topic area. The total weighting of each topic, such as ozone layer protection, is always 1; that value is then broken down attributing each criterion under that topic with a relative significance against the other criteria in that topic. 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.[11]

Several months after the prioritising stage of the research was completed, the Building Research Establishment launched a method of environmental scoring, entitled Ecopoints.[12] This is a unit of measurement for assessing buildings that accounts for the relative significance of different environmental impacts, and is incorporated into both the *EcoHomes* and *Envest* assessments. Focus group studies were made of relevant specialists within the construction industry, who rated a number of environmental impacts in the order of their perceived relative importance. This does not determine the relative significance of the

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[9] Ibid.
[10] The five topics are: ozone layer protection, environmental impact of energy use, indoor environmental quality, resource conservation, and site and transportation.
[11] Ibid.

criteria that are used in the Building Research Establishment's assessments, but does identify a potential route through which to evolve the process of prioritising the criteria of the 'urban house in paradise' beyond the stage reached here, by accounting for the relative significance of the environmental impacts reduced by adopting its benchmarks.[13]

7.3 Methodology

The methodology that was used to prioritise the criteria, to establish a hierarchy between them required identifying four types of ecological degradation. The reduction in impact against each of those parameters that is achieved by moving from the benchmark of the typical dwelling to that of the 'urban house in paradise', in a Deep Ecological sense, was calculated for each of the criteria.

For some of the criteria of the matrix it will be relatively straightforward to determine the relative significance between each, such as those that have common or comparable units of measurement. For these it will be possible to determine a quantitative value for the impact of each, and therefore objectively determine which has the greatest reduction in impact; an example being CO_2 emissions associated with embodied energy, and CO_2 emissions during the period of inhabitation.

However, it may prove difficult to determine the relative significance of the impact of every criterion on equal terms of reference, such as when two criteria do not have a comparable way of defining or quantifying their ecological impact. For example, how can a relative priority be attributed between the ecological significance of the site, and the level of nitrogen oxide emissions?

Another approach to comparing each of the criteria in terms of its own unit of magnitude would be to choose one unit to translate each of the other criteria's benchmarks into. An

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[12] 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.

[13] The identified shortcoming of this unit of assessment is that as an abstract, dimensionless value, not considered in terms of conventional units, it will only identify the ecological benefits of reducing, for example, energy consumption. Because no quantification of that energy reduction can be identified the wider benefits in the relationship between additional capital cost and lifecycle cost saving, which might provide a greater incentive for creating a more sustainable building, cannot be considered. Also,

objective, quantitative comparison can then be made of the criteria, in effect producing a 'league table' of impact. The unit chosen would have to be of high significance in terms of overall ecological degradation, and be appropriate to as many of the criteria as possible. One such quantity could be carbon dioxide emissions. However, this method has two distinct disadvantages. Firstly, bearing in mind that the matrix aims to be as holistic as possible, this ignores other, potentially critical, elements of environmental damage, such as resource depletion. The issue then arises of how to value the impact of criteria that have no significant effect upon CO_2 emissions, yet cause other forms of environmental damage. Secondly, it is inherent that in defining one parameter against which the criteria are assessed will create an orientation, or focus, to the assessment tool, whether this is implicit or explicit.[14] It will also be important to create a method of prioritising that will facilitate the addition of other criteria to the matrix at a later date. Thereby the matrix can be open ended, and respond to the outcomes of further research.

Evidently there is a need to determine some form of common denominator, which has measurable qualities to it, which the criteria can be objectively prioritised against. As identified above, in qualitative terms, the denominator will be environmental sustainability, an understood in the context of Deep Ecology. The challenge, therefore, is to determine measurable dimension, or dimensions, to environmental degradation, against which all of the criteria can be assessed.

The proposed methodology was, therefore, firstly to determine a set of parameters which individually will encompass the key issues of environmental degradation, and which *collectively* will cover the general perspective of ecological sustainability. Each of the criteria will then be assessed against each of these parameters. This will determine their relative significance within that parameter, and a weighting will be attributed on the basis of the position of relative significance. The overall position of relative significance of the criteria will be the sum of the weightings for each parameter.

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whilst the Ecopoint will indicate if one building is more sustainable than another it does not enable the user to determine why that is.

[14] For example, predicating the prioritisation on the level of CO_2 emission attributed by each criterion will create a tool that is orientated toward the total reduction of CO_2 emission created by the benchmarks, as opposed to one that measures the effects of the benchmarks on an overall view of ecological sustainability. Also, there is no single parameter against which sustainability can be defined due to the diversity of effects that contribute to environmental degradation.

The emphasis given to the collective scope of the parameters is important in the context of a Deep Ecology perspective. Arne Naess identifies one of the shortcomings of the shallow ecological movement is that it is largely concerned only with pollution and resource depletion,[15] and furthermore, only with the effects of these impacts where they have a detrimental consequence on the human species.[16] This is in contrast to Deep Ecology, for which pollution and resource depletion are still critical elements, but they are considered in terms of their effects on the environment and nature as a whole. In addition, the concerns of the Deep Ecological view extend beyond this limited remit, to encompass issues such as preserving biodiversity and the effect of humans on any ecosystem.

Each of the criteria will be assessed in terms of the comparative reduction in impact that would be achieved by moving from the standards of the 'typical' dwelling to the standard of the ideal benchmark proposed by the benchmarking process, in chapter 4.0. As an example, in the parameter of global warming, the benchmark for CO_2 Emissions: Inhabitation would create a reduction of 1,794.8 kgCO_2 emissions per annum and the Ecological Weight: Embodied Energy benchmark would create a reduction in greenhouse gas emission the equivalent of 255.8 kgCO_2 emissions per annum. This process will be conducted for each of the parameters. For each parameter, there will be a range of quantitative values of the reduction in impact of each criterion, for example, in terms of global warming, this could range from zero to 2,1223 kgCO_2 emissions per annum. That range will then be translated into a linear scale of weightings. The higher up the scale, the greater the contribution to emission reduction, and therefore the greater the significance of that criterion.

It is not so much the choice of the parameters that is affected by Deep Ecology, although it had a bearing on their selection, but rather the consideration of the scope or range of the effects that each criterion has on the parameters. Although sustainability has social and economic dimensions, the orientation toward Deep Ecology demands that the prioritisation is based upon ecological degradation; socio-economic parameters would be anthropocentric. Rather than a being concerned with human-related effects, the thesis considers the effects on the natural environment as a whole. Therefore the thesis identifies which are most critically important standards to adopt, in terms of the matrix of benchmarks,

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[15] Naess, Arne. 'The Shallow and the Deep, Long-Range Ecology Movements,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995.
[16] Naess, Arne. 'The Deep Ecological Movement – Some Philosophical Aspects,' Op. Cit.

in the pursuit of ecologically sustainable housing in a Deep Ecological perspective. This may propose a radical re-evaluation of the current focus of innovation in new housing, as a part of a paradigm shift from an anthropocentric view of the sustainability of the natural environment to a more ecocentric one.

7.4 Scope

In order to retain a manageable scope to the prioritising, the methodology was restricted to identifying the reduction in direct, measurable impacts against four types of ecological degradation. The potential to expand the scope at a later stage, to include, for example, economic and social sustainability, is identified.

The process of prioritising the criteria requires a tangible factor to be selected against which to assess their relative significance. In the context of the current paradigm of desire to increase the sustainability of the built environment, this factor is environmental sustainability. Of course, sustainability encompasses broader issues than this, including economic and social spheres, and clearly there are criteria within the matrix that will have an impact upon both economic and social sustainability of the dwelling, such as lifecycle cost, utilisation of local resources, qualitative density and space standards. Social sustainability, being partially dependent upon quality of life, will inherently have a subjective dimension. Whilst subjective prioritising is achievable using the methodology selected, refer to 7.5 below, it would significantly expand the scope of the process. It would also be feasible to study the impact of the criteria and their benchmarks on the economic sustainability of the dwelling and its immediate environment, although this would also greatly expand the scope of the task. In order to focus the study in the field of environmental assessment, in which its foundations lie, and also to create a manageable scope to the task of prioritising, the decision has been taken to define the factor against which the criteria are assessed as environmental sustainability.

The scope in assessing the impact of each criterion has been set at the direct effects contributed to be the benchmark standard, and will not include indirect consequential or negligible effects. For example, in terms of the quantitative value of density the area of land that is saved through increasing density is assessed, but the indirect consequential impact of reductions in the level of transport, which is also dependent upon lifestyle factors, have not been included.

Because the analysis is based upon the relative reductions in impact per annum, for the purposes of comparability, certain assumptions had to be made where criteria have more than one variable. For example where criteria are dependent upon time and dwelling area, such as in Energy Consumption: Inhabitation, an assumption has been made on the average number of occupants in the dwelling, based on census data, and this is translated into an area to remove the other variable. It is considered that provided these assumptions remain consistent throughout the analysis for each parameter that this is acceptable, because the purpose of this exercise is to determine the *relative* priority of the impact on ecological degradation, rather than measuring the *absolute* level of impact.[17]

7.5 The Analytic Hierarchy Process

The Analytic Hierarchy Process provides a methodology for converting the four different types of ecological degradation into normalised ratios, so that the cumulative reduction in impacts across the four can be determined for each of the criteria. This provides an overall weighting for the contribution to improving the ecological sustainability of the dwelling made by each of the criteria.

The analysis outlined above will determine the contribution made by adopting each criterion's benchmark to reducing the environmental effect considered by each parameter. Cole proposed the Analytic Hierarchy Process (AHP) as a potential methodology through which to structure components of assessment, the criteria, into a hierarchy, through its ability to, "... disaggregate the problem into a hierarchy of components, determining the priorities for the elements of the hierarchy and finally composing those numbers into overall weights."[18] AHP can be used to provide a structure to the process of normalising the range of impact values determined for the criteria under each parameter of ecological degradation into weightings. Thereby it was possible to convert the reduction in impact against each ecological parameter that is achieved by adopting the benchmarks of the 'urban house in paradise' into a hierarchy of relative significance for the criteria. "The representation is in the

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[17] The next step, were the process of prioritising the criteria to be taken further, would be to undertake a sensitivity analysis. This would study the effects that making changes to the criteria and the assumptions made would have in terms of the overall priority rating that has been determined. It would establish whether or not small changes, such as a slight change in the area of the dwelling or in the number of occupants, would significantly alter the hierarchy of priority.
[18] Cole, Raymond. Op. Cit.

form of a ... hierarchy, with the overall focus or goal situated at the top... In the structure, lower level items are evaluated as to their importance, impact or effect upon the item in the next higher level, and their ultimate effect on the overall goal."[19] Therefore, whilst a general methodology for determining the relative significance between criteria exists, the primary work was in applying this methodology to the criteria of environmental assessment, to determine the most significant in terms of reducing the ecological impact of the dwelling.[20]

If the contribution to the reduction of the ecological impact for all the criteria within a parameter has been determined in a quantitative value, then AHP can be used to normalise the relative contributions on a ratio scale. This is calculated using a simple equation.[21] For example, if the reduction of CO_2 emissions for criteria a, b and c is x, y and z respectively, then the normalised weighting for these will three will be:

for criterion a = $x / (x + y + z)$

for criterion b = $y / (x + y + z)$

for criterion c = $z / (x + y + z)$

The total of the weightings for each parameter will always be 1.000; the weightings are typically taken to three decimal places. If a criterion has no directly measurable or negligible impact, then it is not included within the calculation, and is attributed with a weighting of '0'.

Once the significance weighting has been determined for a criterion against the four parameters, calculating the weighting of the contribution made to the overall reduction of environmental degradation will be achieved by adding together each of the weightings for each parameter. This information can be presented in a spreadsheet, to show the individual weightings for each parameter, and the total for all four.

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19 Wedley, William C. 'The Analytic Hierarchy Process,' *Socio-Economic Planning Science*, January 1990.

20 In the methodology used to derive the Ecopoint, launched after the prioritising was completed, a process of normalisation was used to convert environmental impacts into dimensionless, and therefore comparable, values. Edwards, Suzy of Building Research Establishment's Sustainable Construction Unit. Speaking at *Envest – The Environmental Assessment of Office Buildings* seminar, Glaziers Hall, London, 10 May 2000. That a similar methodology has been used in a kindred, although not identical, process gives confidence in its adoption here. As identified, a shortcoming of Ecopoints is that a variety of impacts have been compressed into a single, somewhat abstract score, which does not allow the user to understand the true nature of the environmental impact the building is making; this was borne in mind when considering how to apply the weighting value within the assessment process.

21 Wedley, William C. Op. Cit.

Should it transpire that the contribution made by a criterion to the environmental effect being measured by a parameter could not be determined as a quantitative value, then AHP has a methodology that can be used to prioritise on the basis of qualitative effects. "[It] provides a general theory of measurement for expressing both tangible and intangible factors."[22] Also if, in the future, social sustainability were added as a parameter to extend the scope of prioritising to the full concept of sustainability, and thereby include subjective dimensions, then AHP would provide the mechanism to do this. Therefore, adopting the AHP method at this stage will allow the research to develop beyond the scope proposed here, to encompass more qualitative areas of sustainability.

7.6 The Parameters of Prioritisation

To assess the improvement in the ecological sustainability of the dwelling, four specific types of ecological degradation have been identified, which collectively constitute a general view of environmental sustainability. These are global warming, pollution, natural resource depletion and ozone depletion. The reduction in impacts against each of these achieved by adopting the benchmarks of the 'urban house in paradise' was then determined.

The four parameters that have been selected to use as the basis of prioritising the criteria are given below. The parameters have been selected from those used in the assessment of Europe's environmental status, *The Dobris Assessment*, prepared by the European Environment Agency Task Force.[23] This is an assessment into the status of Europe's environment, measured against a number of parameters. The number of parameters that are selected for use within the process of prioritisation within the thesis is limited, due to the scope of the work, and so four were selected that covered the primary issues within the Dobris assessment, and could be directly attributed to housing.[24]

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[22] Ibid.

[23] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. *Europe's Environment - The Dobris Assessment*, Copenhagen: European Environment Agency, 1995.

[24] Restricting the parameters to those in which an effect could be directly attributed to a dwelling provided a filter through which to reduce the number to be selected for the purposes of prioritising from

7.6.1 Contribution to the reduction of global warming

The greenhouse effect is considered as one of the largest environmental impacts that man has made upon the planet. The relationship between greenhouse gas emissions and global warming is well established; approximately 30 percent of the total CO_2 emissions in the United Kingdom can be attributed to the dwelling stock. The reduction of greenhouse gas emissions is, therefore, a pertinent part of the agenda of the 'urban house in paradise'.

The greenhouse effect is considered as one of the greatest environmental effects that man has had upon the planet, "There is no single issue in contemporary human affairs that is of greater importance."[25] 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.[26]

The earth's atmosphere has a natural greenhouse effect, without which 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 extent of raising the temperature of the planet. The increase in greenhouse gases in the atmosphere since pre-industrial times is the equivalent to a 50 percent increase in CO_2; the actual level of CO_2 increase has risen by 25 percent, the remainder of the equivalent is due to other greenhouse gases.[27] 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

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the 35 contained within the Dobris assessment report; indirect parameters include transport and agriculture.

[25] Legget, J. (ed). *Global Warming*, Oxford: Oxford University Press, 1990, p. 480.

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

[27] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.

emissions in the region of 60 percent worldwide.[28] It is estimated that the period available for achieving this target is approximately 50 to 60 years.[29]

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 12.5 percent below the levels of emission in 1990, by the period between 2008 and 2012.[30] Evidently this is somewhat below the targets identified by the IPCC.

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.[31] In addition, CO_2 accounts for around 87 percent of the relative contribution of the anthropogenic greenhouse gas emissions in the United Kingdom.[32] The present level of emissions from domestic sources is approximately 157 million tonnes; the goal by the year 2010 is approximately 134 million tonnes.[33] 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.[34] This remains somewhat below the IPCC target of 60 percent reductions.

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. However, it was not until the analysis of 'fossilised' CO_2 concentrations from the past 160,000 years from the Antarctic, in

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[28] Intergovernmental Panel on Climate Change. T*he IPCC Scientific Assessment*, London: Cambridge University Press, 1996.
[29] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. Op. Cit
[30] Department of the Environment, Transport and the Regions. *Climate Change – Draft UK Programme*, London: HMSO, 2000.
[31] Shorrock, L. D. *Future Energy Use and Carbon Dioxide Emissions for UK Housing: A Scenario*, Garston: 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.
[32] 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.
[33] 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.
[34] Ibid. and Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.

comparison with determined corresponding temperature changes, that the correlated relationship between CO_2 concentrations and the average temperatures on the earth was proven, in the mid 1980s.[35] Evidently the reduction of greenhouse gas emissions is, therefore, a part of the agenda of the 'urban house in paradise.'

The consequences of climate change through the greenhouse effect include global warming, sea level rise, increased frequency of storms and less water in rivers.[36] The changes to sea levels, and variation in hydrological and vegetation patterns will invariably have an impact upon the natural environment. For example, sea-level rise through the thermal expansion of water and melting ice will reduce habitat, as will climate change if an ecosystem is unable to adapt or migrate at the rate of change. "Rapid climate change becomes a threat for current biodiversity."[37]

In its consideration of the causes and effects of global warming, the Dobris Assessment considers the changes in emission levels of the principal anthropocentric greenhouse gases. These are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs). Therefore, the prioritisation of the criteria of the 'urban house in paradise' was based upon the reduction in the emission of these gases that is achieved by adopting each of the benchmarks individually. A detailed analysis of the quantitative contribution to reducing global warming emissions that is achieved by moving from the benchmark of a current, typical dwelling to that of the 'urban house in paradise' for each of the criteria is contained in Annexe 5.1, refer to volume 3.

7.6.2 Contribution to the reduction of pollution

The scope of this parameter is based on pollution, an alien waste or by-product that is emitted into another ecosystem, caused by the construction and inhabitation of dwellings, which is an unnatural part of those ecosystems.

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[35] Jouzel, J. et al. 'Vostock Ice Core: A Continuous Isotope Temperature Record over the Last Climatic Cycle,' *Nature*, Number 329.
[36] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.
[37] Ibid., p. 519.

> All organisms have waste and by-products, and these are indeed part of the total biosphere: energy is passed along the line and refracted in various ways. This is cycling, not pollution.[38]

Waste is, therefore, an integral part of any ecosystem. The scope of this parameter is based on pollution, caused by the construction and inhabitation of dwellings, which is an unnatural part of the planet's ecosystems; therefore it considers where it is not retained and managed within one system, but emitted into another. 'Emissions' refers to substances that are of no further use within a system for the purpose of production, transformation or consumption and which are released into the environment, rather than reused or recycled.[39]

In a Deep Ecological approach, pollution is evaluated from a biospheric point of view, based on the effects of a pollutant on any species or ecosystem, as opposed to focussing exclusively upon the effects on human health, which would typify an anthropocentric view.[40] It therefore considers any alien waste or by-product that is emitted into another ecosystem to be a pollutant, even if that pollution is not considered to have a direct or in-direct impact on human well being.

The emissions inventory used in the Dobris assessment, to determine pollution emissions on a European scale, included the following substances: sulphur dioxide (SO_2), nitrogen oxides (NO_X), nitrous oxide (N_2O), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs) and volatile organic compounds (VOCs). As the parameter of contribution to the reduction of global warming includes the emission of N_2O, CO_2, CFCs and CH_4, and the parameter of contribution to the reduction of ozone depletion includes VOCs, these were excluded from the parameter of pollution emissions to prevent double counting. Therefore, the prioritisation of the criteria of the 'urban house in paradise' was based upon the reduction in the emission of SO_2, NO_X, CO, and particulate matter (PM10) which was added to the Dobris pollutants,[41] that is achieved by adopting each of the

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38 Snyder, Gary. 'Four Changes,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995, p. 143.
39 Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.
40 Naess, Arne. 'The Deep Ecological Movement – Some Philosophical Aspects,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995.
41 Particulate matter was included in addition to the pollutants used in the Dobris Assessment as it is a product of the combustion of fossil fuels, which relates significantly to the criteria of the 'urban house in

benchmarks individually. A detailed analysis of the quantitative contribution to reducing pollution emissions that is achieved by moving from the benchmark of a current, typical dwelling to that of the 'urban house in paradise' for each of the criteria is contained in Annexe 5.2, refer to volume 3.

7.6.3 Contribution to the reduction of natural resource consumption

Natural resources can be both renewable and non-renewable, or those with a finite stock. Through Deep Ecology, this parameter considers the loss of any resource of equal importance to the loss of any other, irrespective of its perceived anthropocentric value. The depletion of habitat, with consequent impact upon species loss, is included within this parameter through the consumption of land.

The earth's natural resources are vital to the survival and development of the human and natural environment. Some of these resources are non-renewable, with only a finite stock available, whilst others are renewable, however these are limited by the capacity of natural systems to regenerate themselves; evidence suggests that the rate of anthropocentric depletion of renewable resources may, in some cases, be beyond this threshold.[42]

Adopting the perspective of Deep Ecology to determine the relative significance of each of the criteria in a holistic natural perspective has specific implications for the consideration of resource depletion. In a Deep Ecology sense, all natural resources are perceived to have equal value. This is as opposed to the more anthropocentric viewpoint that resources are only of value if they are have potential uses for the human race, and therefore if no use is known, or expected to be discovered, it does not matter if that resource is destroyed. The economist Peter Drucker epitomises this stance in his observation that it is the entrepreneur who creates value in natural resources, because prior to being possessed and utilised, "every plant is a weed and every mineral is just another rock."[43] Therefore, the criteria will be assessed and prioritised against their relative contribution to the reduction of the consumption of any natural resource. Each resource will be considered to be of equal significance, regardless of any relative anthropocentric value.

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paradise'. Department of Trade and Industry. *Digest of United Kingdom Energy Statistics 1998*, London: HMSO, 1998.
[42] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.

It would be possible to place a 'scarcity weighting' on the resources that are being considered. This would create a higher priority or significance for criteria that contribute to the reduction in consumption of a resource that is scarcer than another. However, as the process of prioritisation is based on the effects of each parameter in a Deep Ecological sense, then the significance attributed to the scarcity of a resource should not be determined on the basis of anthropocentric value. For example, in a comparison between the scarcity of a fossil fuels and water, it would not necessarily follow that scarcity weighting of fossil fuels would be greater, as the scarcity of these is of high significance only in Western anthropocentric terms.

The Dobris Assessment provides a further breakdown of the way in which the exploitation of natural resources can be considered. This includes the differences between renewable and non-renewable resources, the latter of which is considered through fossil energy, prime raw materials and physical intrusion (or modifications to the land surface such as urbanisation or through material extraction by mining). Non-renewable resources included within the Dobris Assessment are fossil fuels, minerals, prime raw materials and land. Both physical intrusions, such as mining, and alteration of the nature of use, such as urbanisation, are included within the land use analysis.

Initially it was envisaged that an additional parameter that would be used in the prioritising process would be the contribution to the reduction of species diversity and habitat destruction. According to the 1995 publication *Global Biodiversity Assessment* by the United Nations Environment Programme,

> ... humans are destroying the Earth's biodiversity at an unprecedented rate, with between 5 and 20 percent of some groups of animal and plant species possibly threatened with extinction in the foreseeable future unless present trends are reversed.[44]

The current rate of extinction is thought to be 50 to 100 times the average natural rate, and in some areas that may rise to 1,000 to 10,000 that rate due to habitat loss.[45] The conservation biologist E. O. Wilson claims that species extinction arising solely from human

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[43] Drucker, Peter. *Innovation and Entrepreneurship*, 1985, p.30.
[44] United Nations Environment Programme. 'Human's Destroying the Earth's Biodiversity', press release, 14 November 1995.
[45] Ibid.

causes has accelerated from approximately 1,000 species per annum in the 1970s to over 10,000 species per annum in the early 1990s.[46] This level of extinction rate has typically preceded each of the previous five mass extinction events in the history of earth.[47] The destruction of biodiversity[48] has implications in both ecocentric and anthropocentric perspectives. It is the base of the stability and sustainable functions of natural systems, and there is evidence that the removal of an ecosystem component, particularly if it is a keystone species, can have negative impacts throughout that system.[49] The Deep Ecology view is concerned with the loss of any life or extinction of any species; whereas in a purely anthropocentric sense, the loss of biodiversity could be associated with a loss of genetic resources, possible food plants, medicines and other potential resources and useful materials.[50]

However, there was difficulty in determining how the impact on species diversity and habitat could be quantitatively determined, in respect of the reduction in impacts of the benchmarks. Principle causes of the decline in Europe's biodiversity, identified in the Dobris Assessment, are loss and fragmentation of natural habitats and urbanisation of existing habitats and pollution, each of which are relevant to the criteria of the 'urban house in paradise'. The only way that appeared quantifiable was the impact from the reduction in land, particularly green space and pollution. However, it would be possible to construe using these effects separately as double counting; therefore the decision was taken to embody the reduction in habitat through the loss of land area within the contribution to the reduction of the consumption of natural resources parameter,[51] and account for pollution only within the contribution to the reduction of pollution parameter. A detailed analysis of the quantitative contribution to reducing natural resource consumption that is achieved by moving from the benchmark of a current, typical dwelling to that of the 'urban house in paradise' for each of the criteria is contained in Annexe 5.3, refer to volume 3.

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[46] Wilson, E. O. *The Diversity of Life*, Cambridge Massachusetts: Harvard University Press, 1992.
[47] More disconcerting is that the increase in the rate of species extinction is faster than for other mass extinctions; these combined factors has lead a number of scientists to conclude that the planet is on the brink of another mass extinction event, brought about by human intervention upon the planet. Edward Wilson interviewed on *State of the Planet*, BBC Television, broadcast 15 November 2000.
[48] A compound of the term biological diversity.
[49] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.
[50] McLaren, Duncan, Simon Bullock and Nusrat Yousuf. *Tomorrow's World*, London: Earthscan, 1998.

7.6.4 Contribution to the reduction of ozone depletion

The depletion of the ozone layer has both anthropocentric and eco-centric impacts; the latter includes the erosion of the base of the ocean food chain. It also has a consequential impact that contributes to global warming.

The ozone layer, which forms a part of the earth's stratosphere, lies approximately 10-50 km above the surface of the earth. Acting as a protective filter, ozone molecules absorb a proportion of ultra-violet radiation from the sun; it has a critical role in the earth's ecological balance due owing to this strong absorption of the biologically damaging ultra-violet radiation.[52] Concern over the depletion of stratospheric ozone, fostered by the United Nations Stockholm conference on the environment, was first raised in the early 1970s. During the 1980s the total column stratospheric ozone over Antarctica decreased by 30 to 40 percent;[53] in October 1987 the average decrease was 50 percent, rising to 95 percent in the zone between 15 to 20 km.[54] Recent evaluations show that seasonal averages of total ozone over Europe were 10 to 13 percent lower than long term averages between 1991 and 1993.[55]

Probably the most commonly perceived effect associated with the depletion of the ozone layer is a potential increase in human skin cancers, due to increased ultra-violet exposure. It has been proposed that a 1 percent decrease in stratospheric ozone could effect an 8 percent increase human skin cancer.[56] However there are other, more ecocentric, effects of ozone depletion. One of these is a reduction in the primary production of phytoplankton,[57] which forms the base of the ocean food chain;[58] this could have consequential effects right up the food chain. It is estimated that a 16 percent reduction in ozone concentration would equate to a 5 percent reduction in primary biomass production arising from loss of

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51 This is a valid approach, as land itself can be considered a natural resource, one reason for which is the provision of habitat. Personal communication from Professor John Whitelegg, Professor of Environmental Studies, Liverpool John Moores University, 7 November 1999.
52 Solomon, Susan. 'Progress Towards a Quantitative Understanding of Antarctic Ozone Depletion', *Nature*, Volume 347, 27 September 1990.
53 Bowman, Kenneth P. 'Global Trends in Total Ozone', *Science*, Volume 239, 1 January 1988.
54 Freedman, Bill. *Environmental Ecology – The Ecological Effects of Pollution*, Disturbance and Other Stresses, London: Academic Press, 1996.
55 Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.
56 Vale, Robert and Brenda. *Green Architecture – Design for a Sustainable Future*, London: Thames and Hudson, 1996.
57 Smith, R. C. et al. 'Ozone Depletion: Ultraviolet Radiation and Phytoplankton Biology in Antarctic Waters, *Science*, Volume 255, 21 February 1992.

phytoplankton, and a reduction in fish stocks of between 6 and 9 percent. It is not only aquatic life that could be affected; there are wide differences in sensitivity to ultra-violet radiation in plant species. In short, "ecological equilibria will continue to be altered if depletion of the ozone layer continues."[59]

Also phytoplankton are a part of the process by which CO_2 is removed from the atmosphere; lower populations will absorb less CO_2 and will therefore feed back into global warming, and the associated implications of that, through increased levels of CO_2 in the atmosphere. Research suggests that in the Antarctic, where the depletion of ozone is concentrated, the reduction of phytoplankton could be up to 12 percent.[60] A 10 percent loss of marine phytoplankton would reduce the oceanic annual uptake of CO_2 by around 5 gigatonnes, an amount equivalent to the annual global emissions of carbon from fossil fuel consumption.[61]

The principal gases that contribute to depletion of the stratospheric ozone layer are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and, to a lesser extent, volatile organic compounds (VOCs).[62] Therefore, the prioritisation of the criteria of the 'urban house in paradise' was based upon the reduction in the emission of these gases that is achieved by adopting each of the benchmarks individually. The emission of CFCs and HCFCs is included within both the parameters of the contribution to the reduction of global warming and the reduction of ozone depleting emissions; as they contributes to both this will not double count their impact. A detailed analysis of the quantitative contribution to reducing ozone depleting emissions that is achieved by moving from the benchmark of a current, typical dwelling to that of the 'urban house in paradise' for each of the criteria is contained in Annexe 5.4, refer to volume 3.

The detailed analysis and results of the impact of each benchmark on the four parameters can be found in Annexes 5.1 to 5.4 in volume 3. The results of the normalised weighting analysis, to determine the overall weighting for each of the criteria across all four parameters, can be seen in the table overleaf.

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58 McLaren, Duncan, Simon Bullock and Nusrat Yousuf. Op. Cit.
59 Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit., p. 526.
60 Welburn, Alan. *Air Pollution and Climate Change: The Biological Impact*, New York: Longman Scientific & Technical, 1994.
61 Ibid.

Criteria	Normalised Weighting				
	GLOBAL WARMING	POLLUTION	NAT RESOURCES	OZONE DEP'N	**TOTAL**
Carbon Intensity	0.016	Counted elsewhere	0.0	0.0	0.016
CO2 Em: Con/Decon	0.004	0.0	0.0	0.0	0.004
CO2 Em: Inhabitation	0.266	0.0	0.0	0.0	0.266
Construction Period	0.0	0.0	0.0	0.0	0.000
Contextual Sig Site	0.0	0.0	0.0	0.0	0.000
Decon/Demol: Recycling	0.0002	0.000	0.022	0.000	0.022
Design Life Span	0.008	0.034	0.005	0.079	0.126
Density: Quantitative	0.016	0.000	0.001	0.0	0.017
Density: Qualitative	0.0	0.0	0.0	0.0	0.000
Diversity	0.0	0.0	0.0	0.0	0.000
Domestic Waste: Recyling	0.025	0.000	0.0004	0.0	0.025
Eco Sig of Site	0.008	0.000	0.0002	0.0	0.008
Eco Weight: Em Energy	0.039	0.078	0.012	0.177	0.306
Eco Weight: Em CO2	0.037	0.000	0.0	0.0	0.037
Energy Con: Construction Process	0.005	0.009	0.001	0.015	0.030
Energy Con: Inhabitation	0.316	0.465	0.610	0.393	1.784
Energy Gen Inhabitation	0.110	0.220	0.092	0.117	0.539
Green Space	0.001	0.0	0.0006	0.0	0.0018
Lifecycle Cost	0.0	0.0	0.0	0.0	0.000
NOx Emissions	0.0	0.004	0.0	0.0	0.004
Other Eco Impacts of Mats	0.0	0.000	0.0	0.0	0.000
Other G'hse Gas Emissions	0.0007	Counted elsewhere	0.0	0.033	0.034
Pollution: Energy Con Inhabitation	0.005	0.053	0.0	0.039	0.097
Procurement	0.0	0.0	0.0	0.0	0.000
Quality of Indoor Env: Pollution	0.0	0.0	0.0	0.0	0.000
Quality of Indoor Env: Daylight	0.0	0.0	0.0	0.0	0.000
Quality of Indoor Env: Ventilation	0.066	0.024	0.162	0.067	0.319
Recycling Construction Waste	0.00002	0.000	0.016	0.0	0.016
Recycling of Building	0.0	0.0	0.000	0.0	0.000
Space Stds: Area	-0.022	-0.040	-0.00250	-0.034	-0.099
Space Stds: Volume	-0.022	-0.040	-0.00327	-0.034	-0.099
Thermal Performance	0.019	-0.001	0.046	-0.010	0.054
Use Recycled Materials	0.0	Counted elsewhere	0.006	0.0	0.006
Use Renewable Material	0.0	0.0	0.018	0.0	0.018
Utilisation of Local Resources	0.0	0.0	0.0	0.0	0.000
Water Con: Construction	0.00006	0.000002	0.00001	0.0000002	0.00007
Water Con: Inhabitation	0.015	0.012	0.003	0.003	0.033
TOTAL	1.000	1.000	1.000	1.000	4.000

Table 5: Normalised weighting for each of the criteria

62 Harrison, R. M. *Pollution: Causes, Effects and Control*, London: Royal Society of Chemistry, 1990.

7.7 Summary

The reduction in impacts against each of the parameters of ecological degradation was determined individually; the Analytic Hierarchy Process was used to convert these reductions into normalised ratios. The four parameter ratios were then summed to provide an overall weighting for each of the criteria, which could then be ordered into a hierarchy, with the most significant in terms of increasing the ecological sustainability of the dwelling at the top.

On the basis of the contribution made to the reduction in environmental impact achieved by adopting the benchmarks of the 'urban house in paradise' over those typical of current new dwelling standards, the process of prioritising establishes the following hierarchy to the criteria. A rating value has also been established, between 0 and 100, so that the relative significance of the criteria to each other can be more easily perceived.

	Criteria	**Weighting**	**Rating**
Most:	Energy Consumption: Inhabitation	1.784	100
	Energy Generation: Inhabitation	0.539	30.2
	Q of I E: Ventilation and Air Tightness	0.319	17.9
	Ecological Weight: Embodied Energy	0.306	17.2
	CO_2 Emissions: Inhabitation	0.266	14.9
	Design Life Span	0.126	7.1
	Pollution: Energy Consumption Inhabitation	0.097	5.4
	Thermal Performance	0.054	3.0
	Ecological Weight: Embodied CO_2 Emissions	0.037	2.1
	Other Greenhouse Gas Emissions	0.034	1.9
	Water Consumption: Inhabitation	0.033	1.8
	Energy Consumption: Construction Processes	0.030	1.7
	Domestic Waste Recycling	0.025	1.4
	Deconstruction/Demolition: Recycling Materials	0.022	1.2
	Use of Renewable Materials	0.018	1.0
	Density: Quantitative	0.017	1.0
	Carbon Intensity	0.016	0.9
	Recycling Construction Waste	0.016	0.9
	Ecological Significance of the Site	0.008	0.5
	Use of Recycled Materials	0.006	0.3
	CO_2 Emissions: Construction Processes	0.004	0.2
	Nitrogen Oxide Emissions from Gas Boilers	0.004	0.2
	Green Space	0.0018	0.1
	Water Consumption: Construction	0.00007	0.00
	Construction Period	0	0
	Contextual Significance of the Site	0	0
	Density: Qualitative	0	0
	Diversity	0	0
	Lifecycle Cost	0	0
	Other Ecological Impacts of Materials	0	0
	Procurement	0	0

	Q of I E: Daylight	0	0
	Q of I E: Pollution	0	0
	Recycling of Building	0	0
	Utilisation of Local Resources	0	0
	Space Standards: Area	- 0.099	- 5.5
Least:	Space Standards: Volume	- 0.099	- 5.5

The gap in the table at the most significant end of the scale is intended to identify the criteria that will be focused upon during the following stages of the research. Those above the gap have been demonstrated by the research to offer the greatest reduction in ecological degradation if their benchmarks are adopted. These are the criteria for which the assessment tool will be designed to measure.

The relative weightings of the criteria can also be represented as a pie chart, which can be seen below. This representation of the relative proportions of the weightings shows the extent to which achieving the Energy Consumption: Inhabitation benchmark, as opposed to the others, will provide the most significant contribution to reducing the environmental impact of a dwelling within the parameters that have been considered above. Its weighting is over three times that of the next most significant criterion.

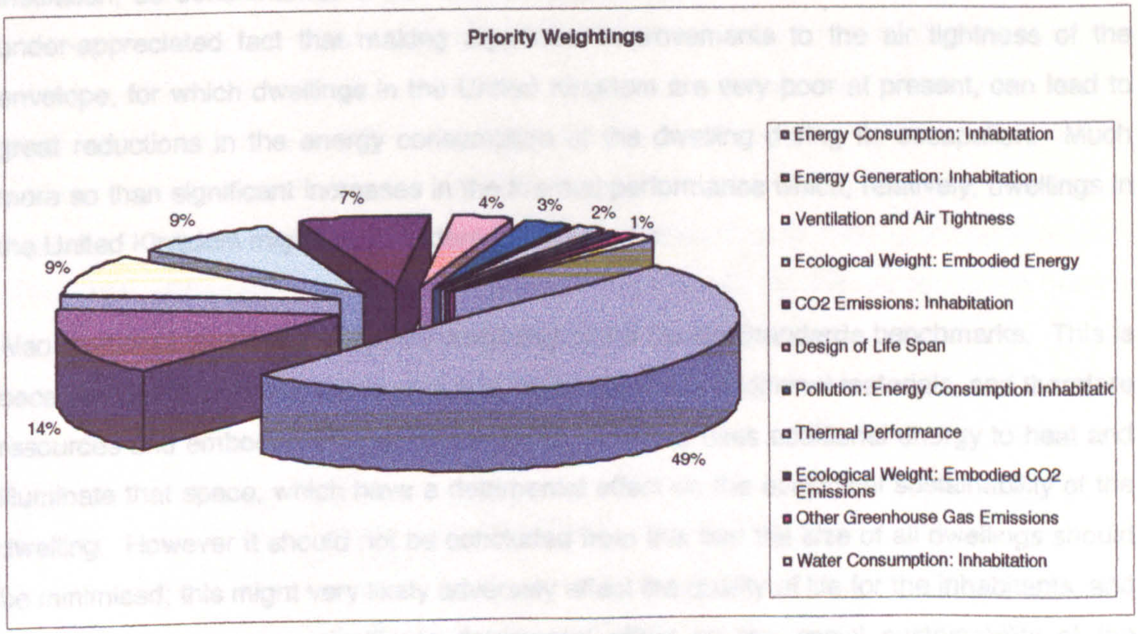

Figure 12: Pie chart of relative priority between weightings

The most significant reduction in the ecological impact of the dwelling would be created through achieving the Energy Consumption: Inhabitation benchmark; it has a relative significance three times that of the next highest criterion, Energy Generation: Inhabitation. It can also be interpreted from the weightings that reducing the energy consumed and CO_2 emitted during the period of inhabitation, to their respective benchmarks, will increase the ecological sustainability of the dwelling by a factor of more than 5 times than would be achieved by reducing the embodied energy and CO_2 to their benchmarks. This demonstrates that reducing the impact during the period of inhabitation is significantly more important to increasing the ecological sustainability of the dwelling than reducing the embodied impacts. However, the embodied impacts should not be considered insignificant, ranking fourth and ninth in the overall hierarchy. Another way to interpret this is that in reducing the impacts to their benchmarked levels, the embodied energy will account for 15 percent of the total lifecycle energy consumption of the dwelling.

From the weightings analysis it can be seen that achieving a highly stringent air tightness benchmark, of 0.17 $ac.h^{-1}$ at 50 Pa, can contribute six times the benefit to improving the ecological sustainability of the dwelling than achieving the very high levels of thermal insulation, as benchmarked under the Thermal Performance criterion. This is due to the under-appreciated fact that making significant improvements to the air tightness of the envelope, for which dwellings in the United Kingdom are very poor at present, can lead to great reductions in the energy consumption of the dwelling during its occupation. Much more so than significant increases in the thermal performance which, relatively, dwellings in the United Kingdom might be considered mediocre for.

Also worthy of note is the negative weighting of the Space Standards benchmarks. This is because creating the additional area and volume requires additional materials, and therefore resources and embodied energy consumption, and also uses additional energy to heat and illuminate that space, which have a detrimental effect on the ecological sustainability of the dwelling. However it should not be concluded from this that the size of all dwellings should be minimised; this might very likely adversely affect the quality of life for the inhabitants, and therefore have a more significant detrimental effect on the social sustainability of the dwelling than the improvement in its ecological sustainability.

Whilst some of the criteria have weightings of zero, this does not mean that in absolute terms they will not have a beneficial effect in increasing the sustainability, even the ecological sustainability, of the dwelling. The score means that no relative significance has been able to be determined within the scope of this assessment.

During the validation interviews on the assessment tool and its methodology, conducted after its design, it was suggested that as the Energy Consumption: Inhabitation benchmark, and therefore the CO_2 Emissions: Inhabitation also, is a dependent factor on benchmarks such as the air tightness and thermal performance, rather than an independent one, it should be excluded in the prioritising process.[63] This is because improving the air tightness and thermal performance may be used as methods by which to achieve the reduction in energy consumption, and consequent CO_2 emissions. As each criterion has been considered independently, this will not affect the overall order of the hierarchy, apart from that Energy Consumption: Inhabitation will no longer be in the list, but will affect the magnitude of the weightings for each which has been calculated in relative terms. The revised weightings are summarised in the following table. However this does not, in any way, negate the fact that achieving the benchmarked reduction in energy consumption during inhabitation will contribute significantly more, to the extent identified above, to reducing the ecological impact of the dwelling than achieving any of the other benchmarked criteria individually will. Also suggested is that ventilation and air tightness be considered independently in the analysis, as they are not dependent upon each other and could be implemented separately. This was achieved by repeating the prioritising process, determining the contribution to the reduction in impacts on the four parameters of ecological degradation, firstly for just the air tightness benchmark, and then just the ventilation benchmark. Integrating these recommendations retrospectively into the prioritising has the following impact on the hierarchy and weightings:

	Criteria	**Weighting**	**Rating**
Most:	Energy Generation: Inhabitation	1.119	100.0
	Ecological Weight: Embodied Energy	0.464	41.5
	Q of I E: Air Tightness	0.408	36.5
	Q of I E: Ventilation	0.344	30.7
	Design Life Span	0.227	20.3
	Pollution: Energy Consumption Inhabitation	0.175	15.6
	Thermal Performance	0.150	13.4
	Ecological Weight: Embodied CO_2 Emissions	0.095	8.5

[63] Refer to Annexe 6.0, Completed Validation Questionnaires, in volume 3.

	Other Greenhouse Gas Emissions	0.089	8.0
	Water Consumption: Inhabitation	0.087	7.8
	Energy Consumption: Construction Processes	0.062	5.5
	Domestic Waste Recycling	0.061	5.5
	Deconstruction/Demolition: Recycling Materials	0.060	5.4
	Use of Renewable Materials	0.047	4.2
	Density: Quantitative	0.043	3.8
	Carbon Intensity	0.037	3.3
	Recycling Construction Waste	0.036	3.2
	Ecological Significance of the Site	0.020	1.8
	Use of Recycled Materials	0.016	1.4
	CO_2 Emissions: Construction Processes	0.011	1.0
	Nitrogen Oxide Emissions from Gas Boilers	0.007	0.6
	Green Space	0.005	0.3
	Water Consumption: Construction	0.00019	0.01
	Construction Period	0	0
	Contextual Significance of the Site	0	0
	Density: Qualitative	0	0
	Diversity	0	0
	Lifecycle Cost	0	0
	Other Ecological Impacts of Materials	0	0
	Procurement	0	0
	Q of I E: Daylight	0	0
	Q of I E: Pollution	0	0
	Recycling of Building	0	0
	Utilisation of Local Resources	0	0
	Space Standards: Area	- 0.192	- 17.2
Least:	Space Standards: Volume	- 0.194	- 17.3

Because the Air Tightness and Ventilation benchmarks are split, their individual weightings drop in comparison to their combined, and both fall below the Ecological Weight: Embodied Energy criterion. Even separated from the Ventilation benchmark, adopting the benchmark of Air Tightness can contribute over two and a half times the benefit in improving the ecological sustainability of the dwelling than achieving the very high levels of thermal insulation benchmarked under the Thermal Performance criterion.

A hierarchy has been established for the criteria that define the 'urban house in paradise'. This is based upon the relative contribution that would be made to increasing the ecological sustainability of the dwelling by moving from the performance of the typical dwelling currently built in the United Kingdom to the standard of the 'urban house in paradise' ideal benchmark, within the limitations of technical feasibility. The next stage of the research was to identify the interrelated links that exist between the criteria, to determine the consequential effect of altering one benchmark upon another. These two stages were then integrated into the development of the assessment tool.

Chapter 8

Interrelationships between the Criteria for the Tool

8.0 Interrelationships between the Criteria for the Tool

With a hierarchy between the criteria established, the research studied another principle inadequacy of existing assessment methods. When designing the methodology for assessing the design of a dwelling against the benchmarked criteria that define the 'urban house in paradise' it was critical to consider the relationships that exist between the criteria; in other words, how altering the performance under one criterion would impact upon the benchmark values of the others. This created the structure through which to evolve the assessment methodology.

The concept of interrelation is a principle integral to sustainability; to determine the consequences of cause and effect relationships in, for example simple ecosystems, requires a fundamental holistic view. Hence the criticism of existing environmental assessment methods, identified earlier, that do not embody such a principle. In addition, the ecologically interrelated and holistic systems view is a part of Deep Ecology,[1] and therefore ties the matrix of criteria and their assessment into the scope of Deep Ecology in another sense.

8.1 Background

Holism and interconnection is a fundamental principle in sustainability, and yet it is absent in existing environmental assessment. The matrix of criteria attempts to codify the interrelated links between each other, so that a holistic representation of the performance of the dwelling is made. Creating these links is critical so that the assessment tool can identify the best overall balance of performance between the criteria.

One of the most significant contributions to knowledge of the matrix of benchmarks and their assessment tool is the interrelation between the criteria, and that these are preference rated to reflect the relative importance of each on the sustainability and environmental impact of new urban housing. Cole has identified that relatively little attention has been paid to the linkages and relationships between the specific issues of the impact of buildings upon the environment. He goes on to state that any attempt to establish linkages between the environmental criteria that are relevant to buildings must be proceeded by a declaration of

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[1] Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995.

the extent of their range. In response to this, the matrix for the 'urban house in paradise' intends create, to as greater extent as is possible, a holistic set of criteria that identify the holistic performance of urban dwellings. Cole concludes by saying that,

> The next generation of environmental criteria for both design and assessment must be set within a framework which offers an overall picture of a building and natural world as an interconnected system, which explicitly acknowledges and defines a coherent link between the individual criteria and provides a means of identifying significance.[2]

In essence, the purpose of the matrix of benchmarks and their assessment tool's methodology is to codify the interrelated nature of the criteria, and their respective benchmarks, within a structure that defines the significance of each criterion in relation to the others, so that a holistic representation of the performance of the dwelling can be created. That one of the primary features not present within existing environmental assessment models is defining or quantifying these relationships between the criteria, demonstrates that they lack this essence of connection; yet holism is one of the fundamental principals of sustainability.

> The challenge to contemporary thinking on the built environment, is the adoption of more holistic models of development, management and planning which recognise this complex web of interrelationships.[3]

The 'nesting' of criteria, advocated by Cole, in which the criteria considered in the matrix can be assessed in successively detailed levels, but each logically connected to other levels,[4] is inherent in an interrelated matrix. Through tracing the routes of interrelation, increasing levels of focus upon each criterion can be reached to determine the consequential effects of other criteria upon the one being considered, thereby allowing an increasing of depth analysis into what effects that benchmark. For example, if one begins by considering the CO_2 emission during the period of inhabitation, one can trace the other criteria that have direct and indirect consequential effects on the level of CO_2 emissions, such as energy

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[2] Cole, Raymond J. 'Prioritising Environmental Criteria in Building Design and Assessment,' in Brandon, P. S., P. L. Lombardi and V. Bentivegna. *Evaluation of the Built Environment for Sustainability*, London: E & F N Spon, 1997, p. 198.
[3] Smith, Maf, John Whitelegg and Nick Williams. *Greening the Built Environment*, London: Earthscan, 1998.
[4] Cole, Raymond. 'Emerging Trends in Building Environmental Assessment Methods,' *Building Research and Information*, Volume 26 Number 1, 1998.

consumption, types of fuel consumed, the carbon intensity of appliances, and indirect effects such as thermal performance and air tightness of the envelope.

Creating responsive links between the criteria is vital in order for a dwelling to achieve the best overall balance of priorities, through the designer being able to determine where the overall performance of the dwelling can be improved through increasing the specification in some areas, whilst being able to ensure that she or he does not over-specify and inadvertently create detrimental impacts from those changes. An example of this is insulation. Increasing the level of insulation will reduce the energy consumed during inhabitation, however it will also increase the embodied energy. Eventually a level will be reached beyond which the reduction in energy consumption will be less than the additional embodied energy, creating a detrimental impact if lifecycle terms. Therefore, the tool will not isolate singular aspects of performance but connect a whole range together, to assist in determining the most sustainable overall balance.

8.2 Chart of Interrelation

Potential links between the criteria were identified in three ways: the literature review of existing environmental assessment methods, dimensional analysis of comparable units used to quantify each of the criteria, and analysis of the stocks and flows diagram used to identify criteria. The links were then represented in a diagram; they were used as the structure through which to evolve the assessment methodology.

With criteria prioritised, it is now possible to construct a diagrammatic representation of the matrix of benchmarked criteria. This can be used to represent the linkages that exist between the criteria within the matrix, and from this these linkages can be quantified. A diagrammatic representation of the interrelated links between the criteria was established, which can be seen overleaf. The links between the criteria were identified by a number of methods. The literature review was used to study any linkages within an existing assessment model, such as the Standard Assessment Procedure. This provides a prediction of the energy consumption of a dwelling; studying its methodology, such as the data required in an assessment, was used to determine if any of the other criteria of the 'urban house in paradise' will impact upon the energy consumption.

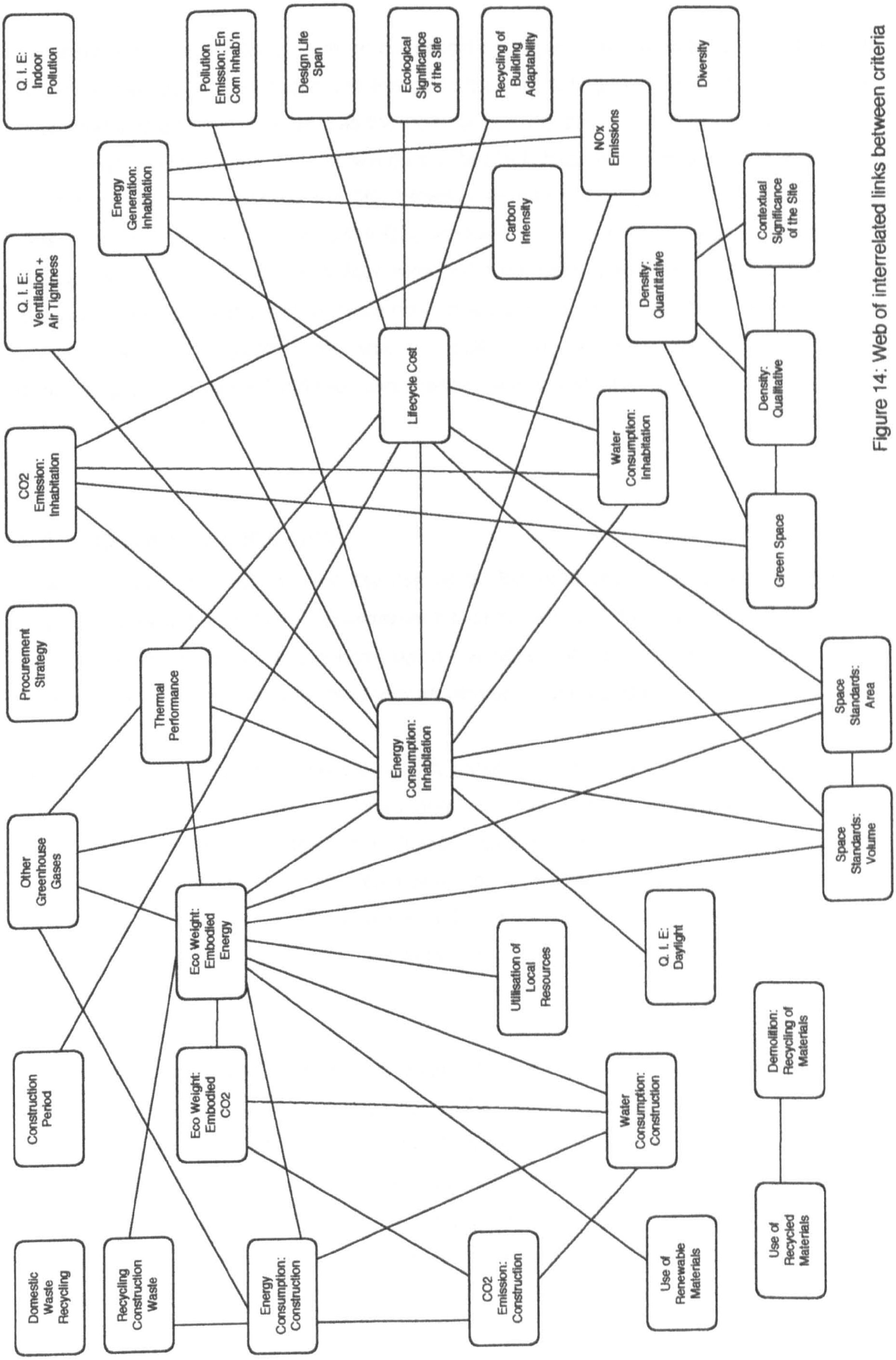

Figure 14: Web of interrelated links between criteria

Comparing the dimension, or unit, of quantification for each of the criteria also identified potential linkages. For example, the energy consumed during the period of inhabitation is quantified in the unit $kWh.m^{-2}.a^{-1}$; as the units to quantify carbon dioxide emissions during inhabitation are $kgCO_2.m^{-2}.a^{-1}$ there will be a potential linkage between these. This link can be determined by quantifying the link between energy consumption (kWh) and carbon dioxide emissions ($kgCO_2$), that is the CO_2 emission per kWh of the energy consumed, or $kgCO_2.kWh^{-1}$; the other values of floor area and time, being common to both, will remain constant. Another example is life cycle cost, quantified in $£.m^{-2}.a^{-1}$, and the longevity of the dwelling, measured in years; the construction cost component, measured in $£.m^{-2}$, will drop if the life span is increased, but the maintenance, energy and water components, measured in $£.m^{-2}.a^{-1}$, will increase.

8.3 Quantifying the Links

The next step was to determine the nature of the relationship that constituted each link. This would enable the assessment tool to account for the magnitude of the effect that one criterion would have upon the other. At this stage the scope of the research began to focus upon the most significant eleven criteria.

With the links that exist between the criteria within the matrix identified it was possible to quantify each of them to determine the magnitude of the consequential effect that altering one of them will have on the other; these algorithms were then be used during the development of the structure of the assessment tool to account for these links. The ordering of the analysis follows the criteria in the order of their significance as identified by the prioritising, links that have already been determined earlier in the process are not repeated in the other direction.

The following text presents the analysis quantifying the interrelationships between the most significant eleven criteria, as identified during the prioritisation, and the criteria within the matrix which those eleven have a link to. The purpose of concentrating upon the most significant eleven criteria is to focus the scope of the work. Each link is considered individually; the algorithm, equation or relationship is determined that calculates the magnitude of the effect that changing the benchmark value of the criterion at one end of the linkage will have upon the value of the benchmark of the criterion at the other end.

- **Link between Energy Consumption: Inhabitation and Energy Generation: Inhabitation**

These are linked in terms of the benchmark for Energy Generation: Inhabitation, which states that it should equal, or exceed the Energy Consumption: Inhabitation value; therefore as the Energy Consumption: Inhabitation changes, either increasing or decreasing, the Energy Generation: Inhabitation benchmark will change by the corresponding quantity. Of course, it will be feasible that the generation will exceed the consumption, and the dwelling by a net provider of renewable energy. Therefore,

Energy Consumption: Inhabitation ≅ Energy Generation: Inhabitation

- **Link between Energy Consumption: Inhabitation and Quality of the Internal Environment: Ventilation and Air Tightness**

The two principle sources of heat loss from a dwelling are conduction through the fabric and from cold air ingress into the dwelling; the two sources of the latter are fresh air entering the dwelling as ventilation and infiltration through the envelope. The ventilation and air tightness benchmarks combine to determine the rate of air entering the dwelling. The heat loss is determined by multiplying the air change rate by the volume of the dwelling and by the specific heat capacity of air. This value is then used in calculating the heat demand of the dwelling to compensate for that loss. This link is accounted for within the SAP calculation to determine the energy consumption of the dwelling.

- **Link between Energy Consumption: Inhabitation and NO_X Emissions from Gas Boilers**

The level of NO_X emissions per kilowatt hour of energy consumption can be established from manufacturer's data for specific appliances. The total NO_X emissions can therefore be determined by multiplying this value by the energy consumption of the appliance.

Gas consumption (space and water heating) x NO_X emission rating

- **Link between Energy Consumption: Inhabitation and Pollution: Energy Consumption during Inhabitation**

This value will be based on the proportion of fuel types used to fulfil the total energy demands of the dwelling, and the level of pollution emitted by those types. The link will be dependent upon the proportion of the total energy consumption for each fuel type, and the emission factor for that fuel type.

(Energy Consumpt'n: Inhab / consumption of fuel type 1) x emission factor 1

\+ (Energy Consumpt'n: Inhab / consumption of fuel type 2) x emission factor 2

where:

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**

Table 6: Pollution emissions per kilowatt hour of consumption for different fuels

- **Link between Energy Consumption: Inhabitation and CO_2 Emissions: Inhabitation**

The link will also be dependent upon the proportion of the total energy consumption for each fuel type, and the CO_2 emission factor for that fuel type.

(Energy Consumpt'n: Inhab / consumption of fuel type 1) x emission factor 1

\+ (Energy Consumpt'n: Inhab / consumption of fuel type 2) x emission factor 2

where:

Fuel	CO_2 Emission factor ($kgCO_2.kWh^{-1}$)
Coal	0.31
Electricity (mains)	0.59
Electricity (renewable)	0
Gas	0.19

Table 7: CO_2 emissions per kilowatt hour of consumption for different fuels

- **Link between Energy Consumption: Inhabitation and Lifecycle Cost**

The equation to determine the cost of energy consumed by the dwelling throughout its life span was determined under the benchmark of Lifecycle Cost.[5]

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

where n = life span

x = energy cost by fuel type:	coal	$= 0.015\ \text{p.kWh}^{-1}$
	electricity (mains)	$= 0.0636\ \text{p.kWh}^{-1}$
	electricity (renewable)	$= 0\ \text{p.kWh}^{-1}$
	gas	$= 0.015\ \text{p.kWh}^{-1}$

z = standing charge, if applicable

- **Link between Energy Consumption: Inhabitation and Space Standards: Area and Volume**

Increasing the volume of the dwelling will increase the space that has to be heated. As the area and volume of a dwelling is used in the SAP assessment methodology to determine the energy consumption of the dwelling, this link will be accounted for. The SAP assessment uses the volume of the dwelling to calculate the heat loss through ventilating that space, depending upon the ventilation rate. The area of the dwelling is used to determine the thermal heat loss through the ground floor, the heat loss as a function of the floor area, and the mean temperature of the dwelling to determine its overall space heat energy demand. The area of the dwelling will also be required to convert the total energy consumption for the dwelling, into the benchmark value that is quantified as a function of the floor area, in $\text{kWh.m}^{-2}.\text{a}^{-1}$.

- **Link between Energy Consumption: Inhabitation and Thermal Performance**

The SAP assessment integrates the value of heat loss through the fabric of the dwelling to the energy that is required to heat it. As the thermal performance of the fabric is increased, the amount of heat that is able to pass through it is reduced, and therefore the energy demand for space heating is also reduced. As the link is already a part of the SAP assessment, as it is adopted as a part of the structure of the assessment tool, the interrelated link is already in place.

- **Link between Energy Consumption: Inhabitation and Quality of the Internal Environment: Daylight**

This link will be dependent upon the quantity of the area of glazing in relation to heat loss and solar gain; the effects on varying the proportion of glazing to the overall area of the dwelling's envelope is accounted for within the SAP calculation; therefore as it is adopted as a part of the structure of the assessment tool, the interrelated link is already in place.

- **Link between Energy Consumption: Inhabitation and Other Greenhouse Gas Emissions**

This link would quantify the greenhouse gas emissions that arise as a consequence of burning fossil fuels to fulfil the energy consumption demands of the dwelling during its inhabitation. As the emission of these gases has been accounted for within other links, CO_2 under the link between Energy Consumption: Inhabitation and CO_2 Emissions: Inhabitation, and CH_4 and N_2O under the link between Energy Consumption: Inhabitation and Pollution: Energy Consumption during Inhabitation, to include the link here would double count their impact.

- **Link between Energy Consumption: Inhabitation and Water Consumption: Inhabitation**

Under the Water Consumption: Inhabitation benchmark it was determined that mains water consumes 0.00055 kWh of energy in its production.[6] Therefore the indirect energy consumed in providing the water for the dwelling will be determined by multiplying the daily consumption by the number of inhabitants over the period of one year.

Energy = (daily potable consumption per person x inhabitants x 365.25 x 0.00055) / area of dwelling

- **Link between Energy Consumption: Inhabitation and Ecological Weight: Embodied Energy**

This link is determined indirectly. The energy consumption of the dwelling will be dependent upon the thermal performance of the fabric; this will be accounted for within the SAP assessment methodology when calculating the energy consumption. The thermal

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[5] Refer to Annexe 3.19, Lifecycle Cost, in volume 3.

[6] Refer to Annexe 3.37, Water Consumption: Inhabitation, in volume 3.

performance of the fabric will be dependent upon the thickness of different materials, in particular the insulation, of the envelope of the dwelling. The quantity of materials will affect the overall embodied energy of the dwelling. Therefore varying the thickness of materials will have an impact on the thermal performance of the fabric, and therefore the energy consumed during inhabitation, and will also have an impact upon the amount of energy embodied within that fabric. The quantification of these links is elaborated upon under Link between Energy Consumption: Inhabitation and Thermal Performance above and Link between Ecological Weight: Embodied Energy and Thermal Performance below.

- **Link between Energy Generation: Inhabitation and NO_X Emissions from Gas Boilers**

If the energy generated is used to replace gas consumption, for example solar water heaters used to provide water heating, then the NO_X emissions will be reduced by the same percentage as that of the energy generated to the energy consumed. For example, if 50 percent of the energy used for space and water heating is provided by solar panels, then the NO_X emissions will be reduced by 50 percent also.

(Energy Generation / Energy Consumption for space and water)
x NO_X emission rating

- **Link between Energy Generation: Inhabitation and Carbon Intensity of Gas Boilers**

If a proportion of the dwelling's energy use is provided by non-CO_2 generating sources, such as solar energy, then the carbon intensity of the delivered energy will be zero. However, this linkage will be accounted for within the carbon intensity calculation itself.

- **Link between Energy Generation: Inhabitation and Pollution: Energy Consumption during Inhabitation**

This link is an indirect one. The proportion of the energy consumed within the dwelling that is produced by renewable sources will have an effect of the level of pollution emissions per kilowatt-hour of that total energy consumption. Within the tool, however, this is accounted for via the link between Energy Consumption: Inhabitation to Pollution: Energy Consumption during Inhabitation, by the assessing the pollution in terms of all of the fuels sources used, including renewable sources generating energy on site.

- **Link between Energy Generation: Inhabitation and Lifecycle Cost**

This calculation represents the capital cost only; there will also be a consequent reduction in the energy costs during the life span of the dwelling which will be accounted for in the Energy Consumption: Inhabitation to Lifecycle Cost link.

Cost of generation plant / Design life span

- **Link between Energy Generation: Inhabitation and CO_2 Emissions: Inhabitation**

The effect on the CO_2 emissions will be the same percentage as the energy generated is of the energy consumed. For example, if the energy generated is 60 percent of the energy consumed, then the reduction in CO_2 emissions will be 60 percent that of what it would be if fossil fuels had been used to produce that energy demand. Within the tool, this link is accounted for when determining the link between Energy Consumption: Inhabitation and CO_2 Emissions: Inhabitation.

- **Link between Other Greenhouse Gas Emissions and Thermal Performance**

This will only be applicable to insulation materials produced with HCFCs as a blowing agent. Firstly, the volume of insulation needs to be determined; this will be related to the U-values of the envelope. From the U-value, the thickness of the insulation (l_i) can be determined; the perimeter of the dwelling, its floor area, roof area and height can then be used to determine the total volume of insulation (v_i). Then,

$$v_i \times 3.44 \text{ kgHCFC.m}^{-3}$$

The consequential effect of an increase in the thickness of the insulation can be measured in the same manner.

- **Link between Other Greenhouse Gas Emissions and Energy Consumption: Construction Processes**

This link will quantify the greenhouse gas emissions that arise as a consequence of burning fossil fuels during the on site construction of the dwelling. The quantity of emissions will vary depending upon the fuel type being consumed.

(Energy consumed on site / consumption of fuel type 1) x emission factor 1

\+ (Energy consumed on site / consumption of fuel type 2) x emission factor 2

where:

Fuel	Gas emissions ($g.kWh^{-1}$)		
	CO_2	CH_4	N_2O
Electricity	590.0	1.350	0.030
Gas	190.0	0.448	0.0004
Petroleum	270.0	0.162	0.12378

Table 8: Greenhouse gas emissions for different fuel types

- **Link between Other Greenhouse Gas Emissions and Ecological Weight: Embodied Energy**

As for the link between Other Greenhouse Gas Emissions and Energy Consumption: Construction Processes, this is dependent upon the quantity of the various fuel types consumed in the extraction and production of materials and components used in the construction of the dwelling. The emission factor is multiplied by the proportion of each fuel of the total embodied energy of the dwelling.[7]

(Total embodied energy / consumption of fuel type 1) x emission factor 1

\+ (Total embodied energy / consumption of fuel type 2) x emission factor 2

The emissions factors in the table of greenhouse gas emissions for different fuel types above can be used for this link also.

- **Link between Quality of the Internal Environment: Ventilation and Air Tightness and CO_2 Emissions: Inhabitation**

This link is an indirect one, and is accounted for in part within the SAP calculation of the energy consumption of the dwelling. The ventilation and air tightness values will affect the level of CO_2 emissions via the value of energy consumption during inhabitation; this will be

[7] Although the data for the ratio of fuels used in the production of different building materials and components does exist, it is held on a confidential database belonging to the Building Research Establishment. Therefore, the proportion of fuels is assumed to be equal between electricity, gas and petroleum. Personal communication: Jane Anderson, Consultant, Centre for Sustainable Construction, Building Research Establishment, 13 January 2000.

accounted for within the SAP calculation, as described under the link between Energy Consumption: Inhabitation and Quality of the Internal Environment: Ventilation and Air Tightness, and then linked to the CO_2 emissions. To take account of this link also would double count the effect.

- **Link between Ecological Weight: Embodied Energy and Thermal Performance**

From the U-value assessment the value of the insulation thickness (l_i) is derived; the perimeter of the dwelling, its floor area, roof area and height can then be used to determine the total volume of insulation (v_i). The density of the insulation (ρ_i) is then used to determine its total mass (m_i). From this standard values (ee_i) can be used to determine the level of embodied energy (ee).

$$m_i = v_i \times \rho_i$$

$$ee = m_i \times ee_i$$

For common insulation materials, the density and embodied energy values are given in the following table.

Insulation Material	Density (kg.m^{-3})	Embodied Energy (kWh.m^{-3})
Mineral fibre slab	30	230
Cellulose fibre	25	133
Expanded polystyrene slab	25	1,125

Table 9: Density and embodied energy of some common insulation materials

An increase in the thickness of the insulation can be measured in the same manner to determine how an increase in the level of insulation will effect the overall embodied energy of the dwelling.

- **Link between Ecological Weight: Embodied Energy and Space Standards: Area**

A change in the area of the dwelling will affect the length of the perimeter, and therefore the quantity of the wall and foundation materials, as well as the area, which will affect the quantity of the roof and floor materials. The increase in embodied energy can be calculated by determining the increase in the volume of materials, and converting that to an increase in mass using the density of the material; the increase in mass is then multiplied by the value of embodied energy per unit mass of each material.

Increase in mass of material (for each type) x embodied energy value

or, m x ee

- **Link between Ecological Weight: Embodied Energy and Space Standards: Volume**

A change in the volume of the dwelling, if it is in terms of ceiling height only, will affect the wall height, and therefore the quantity of materials within the walls. A change in the volume of the dwelling, in terms of both ceiling height and area, will affect the length and height of the perimeter, and therefore the quantity of the wall and foundation materials, as well as the area, which will affect the quantity of the roof and floor materials. Care should be exercised not to double count the affects of and increase in area for both Space Standards: Area and Volume criteria.

Increase in mass of material (for each type) x embodied energy value

or, m x ee

- **Link between Ecological Weight: Embodied Energy and Utilisation of Local Resources**

This will affect the transport component of the embodied energy value. The quantity of materials from which the dwelling is constructed, the distance over which those materials are transported and the mode of transportation will all contribute to quantifying the link. 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.[8]

Energy ($kWh.m^{-2}$) = (mass of material x distance x energy per t per km) / floor area

[8] 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.

- **Link between Ecological Weight: Embodied Energy and Water Consumption: Construction**

It was determined during the benchmark analysis that water consumption has an indirect energy consumption through the energy consumed in its processing and transportation. This link will be dependent upon the quantity of water used in the construction of the dwelling.

$$\text{Energy (kWh.m}^{-2}\text{)} = \text{(water consumption (litres) x 0.00055 kWh.l}^{-1}\text{) / floor area}$$

- **Link between Ecological Weight: Embodied Energy and Use of Renewable Materials**

The embodied energy calculation uses values for embodied energy per unit mass of all the materials used in the construction of the dwelling. Therefore whilst using renewable resources as opposed to non-renewable may have an impact upon the total embodied energy of the dwelling, any variation is accounted for within the embodied energy calculation itself.

- **Link between Ecological Weight: Embodied Energy and Energy Consumption: Construction Processes**

This link exists as the benchmark for Energy Consumption: Construction Process was determined as a proportion of the total embodied energy of the dwelling, quantified by the Ecological Weight: Embodied Energy benchmark. It was identified that the energy used during the on site construction of the dwelling typically accounts for 15 percent of the embodied energy.[9] Therefore the link can be quantified by multiplying by ratio of the energy used on site to the total embodied value.

$$\text{On site energy consumption} = 0.15 \times \text{embodied energy}$$

As the methodology of quantifying the energy consumed on site is an approximation, it is feasible that it could be improved upon. Should this occur, this link may alter or no longer be relevant.

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[9] Refer to Annexe 3.15, Energy Consumption: On Site Construction Processes, in volume 3.

- **Link between Ecological Weight: Embodied Energy and Ecological Weight: Embodied CO_2**

This link will be dependent upon the quantity of the various fuel types consumed in the extraction and production of materials and components used in the construction of the dwelling. The emission factor is multiplied by the proportion of each fuel of the total embodied energy of the dwelling.[10]

(Total embodied energy / consumption of fuel type 1) x emission factor 1
\+ (Total embodied energy / consumption of fuel type 2) x emission factor 2
\+ (Total embodied energy / consumption of fuel type 3) x emission factor 3

As the same presumption of an equal proportion between electricity, gas and petroleum will be made here as above, the equation can be rewritten as follows:[11]

(Total embodied energy x 0.333) x 0.59
\+ (Total embodied energy / 0.333) x 0.19
\+ (Total embodied energy / 0.333) x 0.27

- **Link between CO_2 Emissions: Inhabitation and Carbon Intensity**

CO_2 emissions arising from a gas boiler can be accurately predicted through the carbon intensity value of the gas boiler. The annual consumption of the gas boiler is multiplied by the carbon intensity of the appliance. To covert this to CO_2 emissions, the value is multiplied by the ratio of the relative atomic mass of carbon to the relative atomic mass of carbon dioxide, 3.67.[12]

C emission = gas consumption (kWh) x carbon intensity ($kgC.kWh^{-1}$)
CO_2 emission = C emission x 3.67

[10] The same presumption of equal ratio of fuel types is made because the fuel consumption breakdowns for different materials, although they exist, could not be determined, as they are confidential to the Building Research Establishment.

[11] This is based upon an equal consumption of electricity, gas and petroleum, with one third of the energy multiplied by the respective emission factor.

- **Link between CO_2 Emissions: Inhabitation and Green Space**

Providing green space as a part of the dwelling will, in effect, reduce its net CO_2 output. The link between these two criteria is determined by the ability of green space to assimilate CO_2. The quantitative value of assimilation per unit area was determined in the CO_2 Emissions: Inhabitation benchmark analysis.[13]

$$CO_2 \text{ assimilation} = \quad \text{area of green space} \times 0.660\ kgCO_2.m^{-2}.a^{-1}$$

- **Link between CO_2 Emissions: Inhabitation and Water Consumption: Inhabitation**

This will be the affect that reducing the potable water consumption of the dwelling will have on the CO_2 emissions that are created as a result of energy consumed during its treatment and transportation. The quantity of CO_2 emitted per litre of water, 0.33 $kgCO_2$, was determined under the analysis for the Water Consumption: Inhabitation benchmark.[14]

$$CO_2 \text{ emission} = (\text{daily potable consumption per person} \times \text{inhabitants} \times 365.25 \times 0.33) / \text{area of dwelling}$$

- **Link between CO_2 Emissions: Inhabitation and Space Standards: Area and Volume**

This link is an indirect one. The level of CO_2 emissions arising as a consequence of the area and volume of the dwelling will be due to the energy consumed during the period of inhabitation; this link will be accounted for within the SAP calculation, described under the link between Energy Consumption: Inhabitation and Space Standards: Area and Volume above. To include it here also will double count the effect.

- **Link between CO_2 Emissions: Inhabitation and Thermal Performance**

This link is also an indirect one. The thermal performance will affect the CO_2 emissions during inhabitation due to its affect on the energy consumption during inhabitation. Therefore, this link will be accounted for via the Energy Consumption: Inhabitation to Thermal Performance link, through the SAP calculation, and then the Energy Consumption: Inhabitation to CO_2 Emissions: Inhabitation link.

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[12] Atomic mass of carbon = 12; atomic mass of carbon dioxide = 12 + 16 + 16 = 44; 44 / 12 = 3.67. Serway, Raymond A. *Physics For Scientists & Engineers*, London: Saunders College Publishing, 1990.

[13] Refer to Annexe 3.1, Carbon Dioxide Emissions: Inhabitation, in volume 3.

[14] Refer to Annexe 3.37, Water Consumption: Inhabitation, in volume 3.

- **Link between Design Life Span and Lifecycle Cost**

This link will be dependent upon the components that effect the cost of the dwelling throughout its life span and the length of that life span.

Lifecycle cost = construction cost + maintenance costs + ((energy costs + water costs) x design life span)

However, the links between energy cost and water cost have been accounted for under the links between Energy Consumption: Inhabitation and Lifecycle Cost and Water Consumption: Inhabitation and Lifecycle Cost respectively. Therefore these elements of the link between Design Life Span and Lifecycle Cost should be considered as indirect so as not to double count their impact.

- **Link between Thermal Performance and Lifecycle Cost**

The effect on the construction cost of the dwelling by varying the thickness of insulation is affected by the cost per unit mass of that insulation; labour costs do not have a significant impact.[15] The effect on the life cycle cost of the dwelling by varying the insulation thickness will be dependent upon how the change in thickness affects the energy consumption of the dwelling, and the cost of that energy. The impact on the lifecycle cost can be summarised in the following equation.

Cost of insulation (C_i: £.m^{-3}) x volume of insulation (v_i: m^3) - energy consumption: inhabitation costs

or, $$(C_i \times v_i) - \sum_{n-1}^{0} x \,.\, 1.02^n$$

where C_i = cost of insulation per unit mass (£.m^{-3})
v_i = volume of insulation (m^3)
n = life span
x = energy cost by fuel type:

x = energy cost by fuel type:	coal	= 0.015 p.kWh^{-1}
	electricity (mains)	= 0.0636 p.kWh^{-1}
	electricity (renewable)	= 0 p.kWh^{-1}
	gas	= 0.015 p.kWh^{-1}

z = standing charge, if applicable

[15] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.

- **Link between Thermal Performance and Ecological Weight: Embodied CO_2**

This link is an indirect one. The level of thermal performance will affect the quantity of insulation in the dwelling, which will affect the quantity of embodied energy; it will be the change in the quantity of embodied energy that will vary the Ecological Weight: Embodied CO_2 value. Therefore this link will be accounted for via the link between Thermal Performance and Ecological Weight: Embodied Energy and then the link between Ecological Weight: Embodied Energy and Ecological Weight: Embodied CO_2, so as to avoid double counting.

- **Link between Ecological Weight: Embodied CO_2 and Space Standards: Area and Volume**

This link is also an indirect one. A change to the area or volume of the dwelling will affect the quantity of material from which it is constructed, which will affect the level of embodied energy; it will be the impact upon the level of embodied energy that will affect the Ecological Weight: Embodied CO_2 value. Therefore this link will be accounted for via the link between Space Standards: Area and Volume and Ecological Weight: Embodied Energy and then the link between Ecological Weight: Embodied Energy and Ecological Weight: Embodied CO_2, to avoid double counting.

- **Link between Ecological Weight: Embodied CO_2 and Water Consumption: Construction**

As determined during the benchmark analysis, water consumption has a consequent emission of CO_2 through the energy consumed in its processing and transportation. This link will be dependent upon the quantity of water used in the construction of the dwelling.

$$CO_2 \text{ emission } (kgCO_2.m^{-2}) = \text{(water consumption (l)} \times 0.33\ kgCO_2.l^{-1}) / \text{floor area}$$

- **Link between Ecological Weight: Embodied CO_2 and CO_2 Emissions: Construction Processes**

As for the link between Ecological Weight: Embodied Energy and Energy Consumption: Construction Processes the quantitative link will be based upon the proportion of the total embodied energy of the dwelling, quantified by the Ecological Weight: Embodied Energy benchmark. It was identified that the energy used during the on site construction of the dwelling typically accounts for 15 percent of the embodied energy; it is assumed that the ratio of fuel types will remain constant, and therefore the link can be quantified by multiplying by the same ratio of 15 percent.[16]

$$\text{On site } CO_2 \text{ emissions} = \qquad 0.15 \times \text{embodied } CO_2 \text{ emissions}$$

- **Link between Water Consumption: Inhabitation and Lifecycle Cost**

The relationship between the water used in the dwelling during its period of inhabitation and the lifecycle cost of the dwelling will be dependent upon the quantity of annual water consumption, the cost of water, and the life span of the dwelling.

$$\sum_{n-1}^{0} (x \times \text{number of inhabitants} \times 365.25) \times 1.02^{n}) + z$$

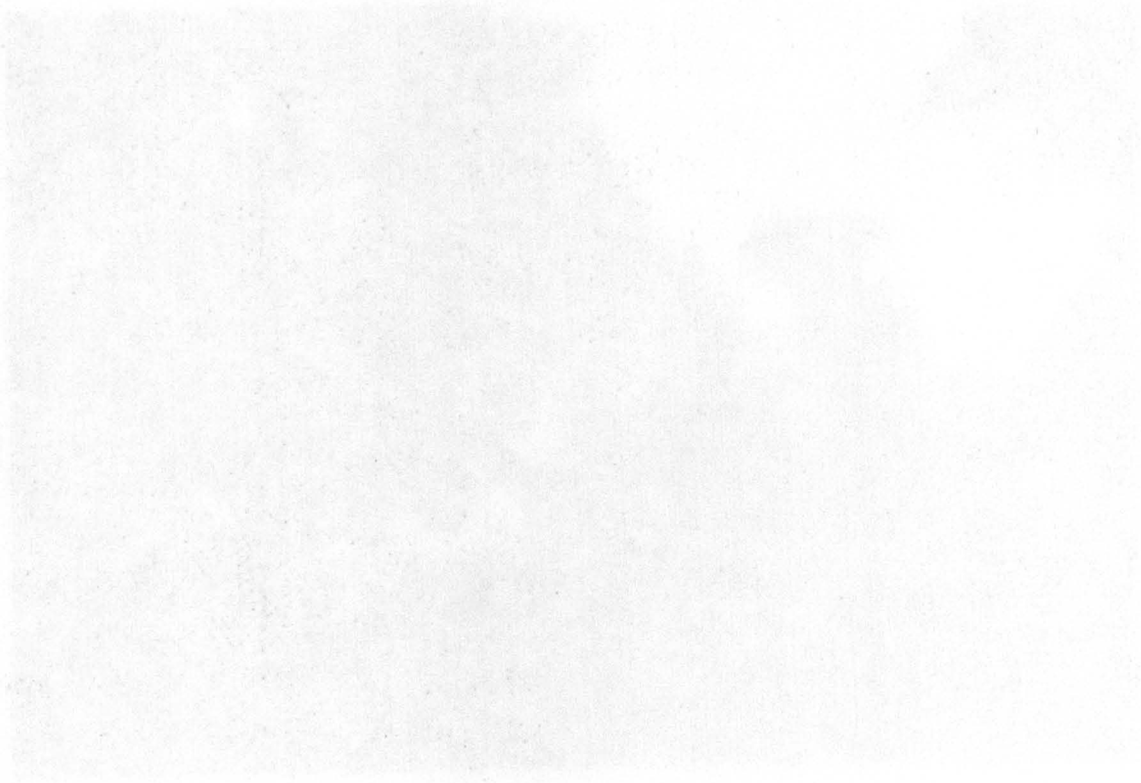
where n = life span

x = water cost = 0.067p.l^{-1}

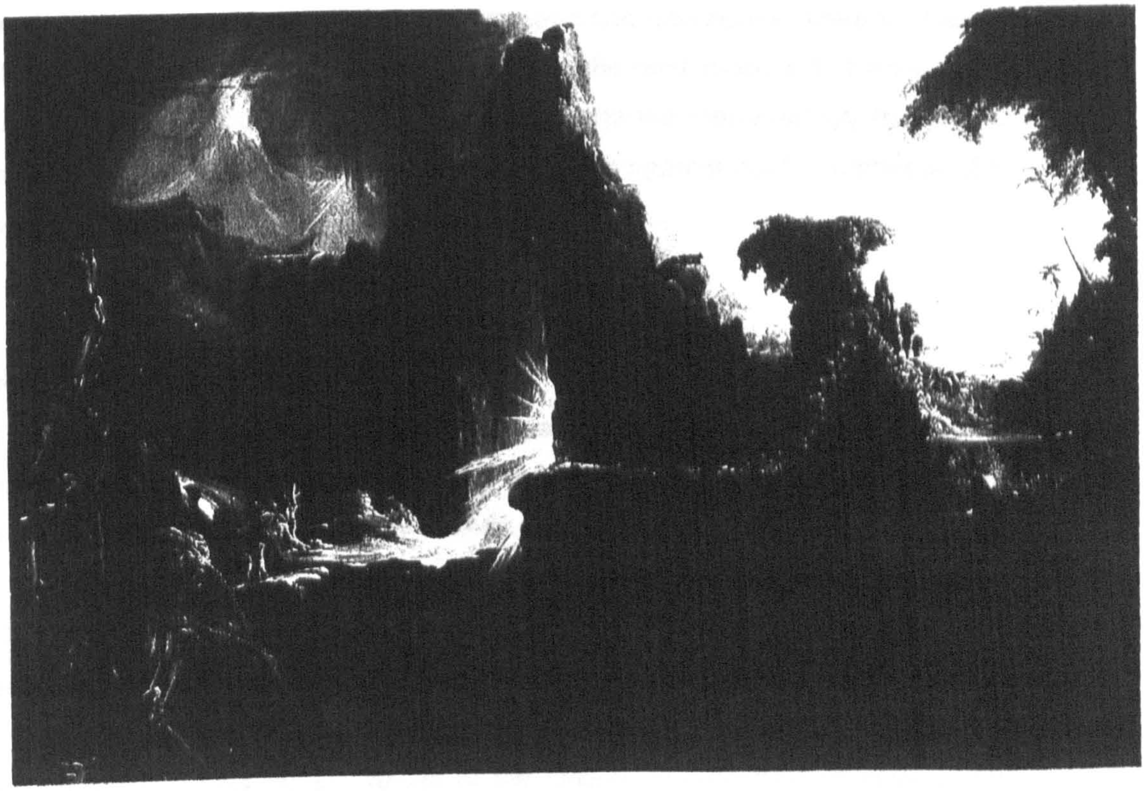
z = standing charge, if applicable

With the interrelated links between the criteria of the 'urban house in paradise' identified and quantified, it is now possible to develop a methodology for assessing a design of any dwelling against the benchmarks. This assessment protocol will utilise these linkages and relationships between the criteria to enable a designer to attain the most sustainable balance of performance. The first stage in designing the tool is to identify the process for calculating each benchmark.

[16] This assumption is based upon the data that was available. More detailed further research may reveal that the ratio of fuel types varies between pre site and on site energy consumption, such as an increase in petroleum. This could be accounted for in a similar manner to which fuel type variations are accounted for in the link between Energy Consumption: Inhabitation and Pollution: Energy Consumption during Inhabitation.



Chapter 9



The Design of the Tool

9.0 The Design of the Tool

With the eleven most significant criteria identified, in terms of the potential reduction in the ecological impact of the dwelling, and the interrelated links that exist between those criteria both identified and quantified, the next stage of the work was to design the assessment tool itself. This would become the methodology that could be used by an architect to assess a design of a dwelling against the benchmarks of the 'urban house in paradise'.

9.1 Brief

The tool should enable any dwelling type to be assessed against the criteria of the 'urban house in paradise'; and be responsive to altering the performance to determine the most ecologically sustainable solution.

One of the aims for the thesis is to produce a design tool that will enable a project to be assessed in terms of its performance against the benchmarks of the 'urban house in paradise'. Once an initial assessment has taken place, the assessment tool will then allow the designer to vary certain values of the criteria, to determine whether or not that will improve the overall balance of priorities, and therefore improve the overall ecological sustainability of the dwelling.

The ambition is to develop a model that is sufficiently robust to be directly applicable or appropriate to the majority of types of dwelling and dwelling construction; and that is capable of being adapted to suit others if they do not immediately fit into the model.

9.2 Foundations

The SAP assessment was used as the basis from which to develop the tool; as a worksheet it could be broken apart and expanded upon to assess the other benchmarks. Applied methodology, such as U-value calculations, could be inserted or new assessment algorithms developed, such as the pollutant emissions.

The intention is made throughout the design of each section of the tool that where a piece of applied work is used or adapted into the tool, it is the most appropriate to the situation, and is adopted from the most reputable and appropriate source to ensure the robustness and accuracy of the final version of the tool. An example of this is the U-value calculations used in determining the energy consumption of the dwelling during inhabitation; the methodology is based upon the equations used in the Chartered Institute of Building Services Engineers' *CIBSE Guide – Volume A*,[1] which could be considered as the standard text for such data.

As discussed under the methodology for the assessment of the Energy Consumption: Inhabitation benchmark[2] models already exist to determine the energy consumption of a dwelling, such as the Standards Assessment Procedure (SAP)[3] and Building Research Establishment's Domestic Energy Model (BREDEM).[4] Rather than duplicating work the extensive work that has been undertaken to develop these, the decision has been taken to use an existing model to determine the energy consumption of the dwelling. The decision has also been taken to base this on a worksheet version of an existing model; this is for two reasons. Firstly it will allow a full set of algorithms to be developed for the tool, rather than relying on an energy consumption value produced by computer software that is then inserted into the matrix. Of course, once all of the algorithms are determined, it would be feasible to develop a variant of a computer version of an existing model that is expanded to take account of all of the criteria of the matrix, although this would most likely have to be done by the authors of the original software model.

The existing worksheet that has been selected to base the matrix worksheet on is to be a combination of both the SAP and BREDEM models.[5] Whilst the SAP model is more detailed than the most recent worksheet BREDEM model, as BREDEM is now only issued on software, it does have two principal shortcomings. Firstly, it takes no account of the energy consumed by lights and appliances and cooking, although does include them as internal gains. Secondly, the SAP value is based upon fuel costs, and so varying the fuel cost, such as on and off peak electricity, can make the dwelling appear more efficient. As the SAP worksheet is more detailed than that of the BREDEM model, it will become the initial structure of the tool.

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1 Chartered Institution of Building Services Engineers. *CIBSE Guide – Volume A: Design Data*, London: CIBSE, 1986.
2 Please refer to Annexe 3.16, Energy Consumption: Inhabitation, in volume 3.
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 Anderson, B. R. 'Energy Assessment for Dwellings Using BREDEM Worksheets', *IP 13/88*, Garston: Building Research Establishment, November 1988.

These two shortcomings will be overcome by adapting the SAP methodology during the development of the tool's worksheet. The BREDEM method of assessment for consumption arising from cooking, lights and appliances will be integrated into the overall consumption value. The consumption arising from space and water heating will be determined by adapting the latter stages of the SAP model, so that the benchmark derived is based on actual energy consumption, rather than converting to the energy cost value at the penultimate step, as in the case of the SAP worksheet.

Dr Brian Anderson of BRECSU revealed areas that they consider could potentially be improved upon in the SAP assessment.[6] These include, that the hot water energy requirement calculation and internal gains are based upon the floor area of the dwelling; the values, in tabulated form, are based on measured consumption from a range of dwelling sizes, and the table is derived by interpolating between the measured values; these values are now somewhat out of date. A significant improvement would be to update the table, or base the energy requirement on the actual predicted water consumption and gains of the dwelling. The latter method would allow account to be made for low consumption appliances and fittings, such as low flow showerheads or flow restrictors. An attempt is made to overcome these criticisms; creating the methodology for amending these shortcomings creates a relevant advance upon the existing SAP assessment.

As some of the other criteria of the matrix are a part of the calculation, such as thermal performance, using the worksheet as an initial basis allowed the methodology to be adapted and expanded to be able to respond to varying these values. This is the second reason for using an existing worksheet as the start point; it could be broken apart, developed and expanded to account for the interrelated links between the criteria and their benchmarks. For example, the SAP model has, under the Heat Losses section, a point of entry for the U-values, but no breakdown of the U-value calculation. Expanding the worksheet at this point allowed the U-value to be altered by changing materials and their thickness. These changes were then be picked up elsewhere in the worksheet to determine how they affect the embodied energy and embodied CO_2 emission benchmarks, amongst others, as well as the energy consumption and CO_2 emissions of the dwelling when inhabited.

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[5] The use of the SAP methodology in environmental assessment has a precedent; it is used by the Building Research Establishment for the calculation of CO_2 emissions in the *EcoHomes* assessment.
[6] Personal communication, Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.

9.3 Dimensional Information

The first section of the assessment tool establishes basic information on the size of the dwelling, including its area, perimeter, height, volume and number of storeys.

The SAP methodology already includes steps to determine the total floor area and total volume of the dwelling. This section was expanded to include the number of storeys and the length of the dwelling's perimeter; these are used later in the worksheet to determine the embodied energy of the dwelling. The latter is of particular significance, as it can be varied to determine how changing the plan form of the building will impact upon other criteria. It could be possible that information required at this stage could be used during the Energy Consumption: Inhabitation calculation, by linking dimensional information to the area of the elements that constitute the heat loss parameters, such as the area of walls, roof, ground floor and windows. This would allow the user to determine how changing the area of plan form of the dwelling, for example, would affect the energy consumption.

9.4 Space Standards: Area and Volume

In conjunction with the number of inhabitants, the dimensional information is used to calculate the space standards benchmarks.

Although these were not within the prioritised criteria, it was a straightforward process to include their assessment within the tool, as through the dimensional information analysis, the total area and volume of the dwelling was already being determined, and the number of occupants was required for the water consumption calculations. Therefore the inclusion of the Space Standards benchmarks only required the addition of two simple algorithms; this was considered justifiable, as the tool will assess two more benchmarks. They are included for information only, and do not constitute a part of the overall scoring, which is based purely on the primary prioritised criteria.

9.5 Ventilation and Air Tightness

The air tightness is entered into the tool as a design target, informed by comparable examples. The ventilation rate is determined as a part of the SAP methodology.

These two values are combined to determine the effective air change rate, and subsequently the heat losses attributable to that.

The SAP assessment makes an approximate estimation of structural infiltration on the basis of the construction technology used, and also allows for a measured air tightness test if the assessment is being conducted post completion.[7] Because one of the benchmarks for the 'urban house in paradise' is air tightness, the worksheet is adapted to require the insertion of the target benchmark. This is supported by a table of air tightness values for a range of construction technologies, precedents and related regulatory standards from both England and Europe, from the current typical dwelling to the benchmark of the 'urban house in paradise', so that an appropriate target can be selected. Being able to determine the effect of varying the air tightness benchmark upon the annual energy consumption of the dwelling is a useful attribute of the tool, in particular with the increasing attention on air tightness and proposals to include a minimum standard in the next revision to the Building Regulations.[8] A step is included in which to enter the target air tightness value. As this has an impact upon the effective air change rate, and ultimately the energy consumption, the tool can be used to demonstrate the impact upon varying this value on the energy consumption of the dwelling during its inhabitation, and therefore the significance of the air tightness value.

The ventilation rate is calculated as a part of the SAP process, and can therefore be identified as a benchmark at the appropriate stage, which is the 'Effective air change rate' value. The SAP worksheet has steps to calculate the ventilation rate from both mechanical and natural systems; in both cases the infiltration from the envelope is added to the predicted ventilation rate. The constant of 0.5 is used in the SAP worksheet as the minimum level of ventilation that will be expected; it is considered that if the predicted ventilation rate falls below this, in a very air-tight naturally ventilated dwelling for example, the inhabitants will open windows to raise the ventilation rate.[9] This constant value is used for both mechanical and natural systems.

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[7] The air tightness of the dwelling is a design value, as it will be dependent upon the method and quality of construction, and therefore cannot be measured until the dwelling is complete.

[8] 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.

[9] Personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.

9.6 Thermal Performance

To calculate the thermal performance, the SAP worksheet is expanded to include steps for entering details of the materials from which the dwelling is constructed; these are used to calculate the thermal performance based upon standard equations. The consequential effects of varying material thickness on the thermal performance, energy consumption and embodied energy can therefore be accounted for.

The SAP worksheet requires the U-values for the different elements of the fabric of the dwelling to be used in the calculation. At this point the sheet is expanded to include the calculation of these values. 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:

$$U \text{ value} = 1 / R_t$$

where R_t = sum of resistances

$$R_t = R_{so} + (\text{thickness}/\lambda) + (\text{thickness}/\lambda) + \text{etc} + R_{cav} + R_{si}$$

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 ($W.m^{-1}.K^{-1}$)

The equation will vary according to specific 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 have been used to derive the methodology of the U-value calculations in the worksheet; these are Volume A of the *CIBSE Guide* and *Part L* of the Building Regulations.[10]

[10] 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*, Garston: Building Research Establishment, August 1994; Anderson, B. R. 'The U-value of Solid Ground Floors with Edge Insulation, *IP7/93*, Garston: Building Research Establishment, April 1993; and Anderson, B. R. 'The U-value of Ground Floors: Application to Building Regulations, *IP3/90*, Garston: Building Research Establishment, April 1990.

The thermal performance of a timber frame wall can be derived from the following equation:[11]

$$R = 1 / (F_t / R_t) + (F_{ins} / R_{ins})$$

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:

$$U = 1 / (R_{inner} + R_{cav} + R_{outer})$$

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*.[12] The fact that the former is based upon values that already within the assessment methodology, namely perimeter and area, means that it has an advantage in terms of the interrelation between parameters. However, a disadvantage of the former is that it is based upon a wall thickness of 300 mm. In a highly insulated dwelling the external walls could be significantly thicker than that; for example, in Aire 8100 dwelling, from drawn studies Four and Five, 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 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:

$$U_{floor} = (2 \times \lambda_e / b \times \pi) \ln (2 \times b + w / w) \exp (b / 2 \times l)$$

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[11] Department of the Environment and the Welsh Office. *Approved Document L*, London: HMSO, 1995

[12] 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 demonstrates that each is appropriate as the other in terms of accuracy.

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:

Sum of resistances $R_t = R_A\cos\theta + R_{cav} + R_B$

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 (θ = 0 if flat roof)

By expanding the worksheet to include the U-value calculation, the type of material and its thickness can be varied to determine how this will affect the thermal performance, to bring it closer to the benchmark of the 'urban house in paradise'. This will have a consequential effect on the energy consumption calculations, which will be interrelated to this value. The value of its thickness can then be used later in the worksheet to determine the embodied energy of the material in the dwelling, therefore the consequential effects of varying that value can be determined also. The effect of changing insulation materials in terms of different thermal conductivity and embodied energy values can also be quantified.

It is a possibility that design target U-values will be used. Such target values can be entered at the respective step, and the energy consumption arising from that value will then be determined. This will allow a designer either to determine the energy consumption for a given U-value, or to determine the U-value that is required to achieve a desired level of energy consumption. The designer may then work from that U-value to determine the element's construction, such as the thickness of insulation required to achieve that U-value, and use the assessment tool to validate that it achieves the target value.

9.7 Water Consumption

A value for the total water consumption for the dwelling is determined on the basis of typical consumption, accounting for any water saving fittings or appliances; this can also determine the predicted hot water consumption and consequent energy demand. The contribution of rainwater harvesting is then calculated, accounting for rainfall by location, area of collecting surfaces and the storage available.

The first value to be determined will be the anticipated level of water consumption within the dwelling. This will commence with the mean value of 160 litres per person per day, and be decreased using tabular data according to water saving fittings and appliances within the dwelling, such as low flow showers, low flush and composting toilets. This will constitute one benchmark. Multiplying this value by the designed occupancy level will give a value of the predicted consumption within the dwelling; the predicted potable consumption can be determined by subtracting rainwater consumption, where applicable. The table can also be used to determine the quantity of hot water consumed within the dwelling, for the purposes of calculating the energy consumption from hot water heating; this is an adaptation of the method used in the SAP worksheet, in which the value is based on floor area, and has previously been identified as a possible area of improvement in its methodology.

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.[13] To account for annual 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,

$$y = (1.8 \times \text{area of collection} \times \text{rainfall}) / 1095$$

The potable water consumption is then be determined by subtracting the potential quantity if rainwater, y, from the total predicted consumption within the dwelling. To account for

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13 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.

drinking and food preparation, the potable consumption must be equal to or greater than 6.5 litres per person per day. This value was determined as the mean consumption for this purpose during the process of benchmarking.[14]

This calculation assumes that sufficient storage capacity is available, which is dependent upon the predicted level of consumption; from precedent, it is suggested that the storage capacity should be around 50 times the daily consumption of the dwelling to account for periods without rain.[15] If only a percentage of this storage capacity is available, the rainwater consumption within the dwelling is reduced by that proportion. The benchmarks of potable water consumption and rainwater consumption are then determined by dividing the two values of consumption within the dwelling by the designed occupancy.

To account for the shortcoming of the SAP worksheet, of basing the energy required for water heating on outmoded consumption values, the predicted consumption of hot water is also determined. From this value the energy required to heat this water can be calculated. The specific heat capacity of water is 4,186 $J.kg^{-1}.K^{-1}$,[16] or 1.16$Wh.l^{-1}.K^{-1}$;[17] the difference in temperature between the water before and after it is heated is assumed to be 36 °C.[18] Therefore, the energy required to heat the water, in $kWh.a^{-1}$, can be determined by the following equation, in which the daily consumption for the dwelling is x:

$$\text{Energy requirement } (kWh.a^{-1}) = (x \times 1.16 \times 36 \times 365.25) / 1{,}000$$

The distribution losses in the SAP assessment are 17.7 percent of the energy consumption requirement; therefore this value is be updated on the basis of the energy requirement determined on the basis of predicted consumption. Standing losses from the cylinder, if applicable, are accounted for by the SAP assessment under the storage loss factor table. Now that the energy requirement for water heating is proportional to the consumption, the

14 Refer to Annexe 3.37, Water Consumption: Inhabitation, in volume 3.

15 BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community', *General Information Report 53*, London: HMSO, October 1998. This value is derived from a design for an autonomous dwelling with rainwater storage of 25,000 litres, designed for 4 people. The daily consumption was determined on the basis of the water saving appliances specified for the dwelling, such as composting toilet and low flow rate fittings.

16 Serway, Raymond A. *Physics For Scientists & Engineers*, London: Saunders College Publishing, 1990.

17 As the mass of 1 litre of water is one kg, no conversion factor is needed to translate between the heat capacity per kg and per litre.

18 It is assumed that water is stored in a header tank and is at the same temperature as the dwelling, say 19 °C, and that the water is heated to 55 °C; if the difference in temperature is otherwise, the value can be adjusted accordingly. For example, if the header tank is outside the insulated space, if it is in

subsequent steps to determine the incidental gains from water heating within the SAP assessment are also proportional to the consumption.

9.8 Energy Consumption: Inhabitation

The SAP assessment used as the foundation from which to build the tool provides the methodology to determine energy consumed by space and water heating; this is expanded to account for energy consumed by lighting, appliances, cooking, pumps and fans. Enabling different efficiencies of lighting and appliances to be accounted for further advances the methodology.

One of the primary reasons for using the SAP methodology as an initial framework for the assessment tool is that it provides a value for the energy consumption for space and water heating. A criticism that has been identified by the thesis is that whilst it takes account of incidental gains made from lighting and domestic appliances to the heating demand for the dwelling, no account is made of the energy that is consumed by these functions. This is a situation in which the tool integrates steps in the BREDEM model, which does take these factors into consideration. By using tabular data, values are provided for the energy consumption per annum for both cooking and lighting and appliances. However, this is expanded beyond the BREDEM model to include scenarios based on energy efficient appliances and lifestyles. These are based on the scenarios of increased efficiency for achieving the zero CO_2, zero heating and autonomous standards in *General Information Report 53.*[19] This is one way in which the assessment methodology can take account of behavioural patterns of the dwelling's inhabitants.

It is possible to take this further, and to use actual values for energy consumption by lighting and appliances. The consequent heat gains arising from these sources can then be established in a similar manner. Under European Union guidelines, all appliances must display their annual energy consumption, and these values could be used when specifying white goods, if appropriate, to improve the accuracy of the value for energy consumed by lighting and appliances. This will be particularly relevant where highly efficient appliances are to be used. The consumption of some common domestic appliances is summarised in

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an attic space where the insulation is laid over the ceiling, the mean temperature difference will be between 6 and 55 °C, and therefore 49 °C.

[19] BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community'.

the table below, and where possible low, medium and high efficiencies included.[20] If the energy consumption of an appliance is given in watts, the predicted annual consumption in kWh.a^{-1} can be determined using the following equation:[21]

$$\text{Consumption (kWh.a}^{-1}\text{)} = (\text{wattage} \times \text{hours used per day} \times 365.25) / 1{,}000$$

Domestic Appliance	Annual Energy Consumption (kWh.a^{-1})		
	High Efficiency	Medium Efficiency	Low Efficiency
Appliances			
Fridge	240	475	595
Washing machine	142	156	190
Dishwasher	133	193	256
Tumble dryer	475	523	562
Kettle	-	218	-
Television	-	164[22]	-
Video	-	52	-
Personal computer	3[23]	175	350
Cooking			
Cooker[24]	300	410	656
Microwave oven	-	46	-

Table 10: Annual energy consumption of a selection of domestic appliances

Steps are available in the tool to enter the consumption from electrical appliances; a table of low, medium and high efficiency versions of those appliances is included as examples in the event that the specific consumption of an appliance is not known. The sum of the consumption for all of the anticipated appliances can then be entered into the tool.

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[20] Sources for this data are based upon both collated data and Brenda and Robert Vale. *The New Autonomous House – Design and Planning for Self-Sufficiency*, London: Thames and Hudson, 2000. The scenarios of high, medium and low efficiency for white goods are based upon the consumption of appliances with 'A', 'C' and 'E' ratings in the European standard classifications.

[21] 365.25 is used to convert the consumption into an annual value, accounting for leap years.

[22] As with other values, the consumption may vary if the appliance is used intermittently, for example a television or computer, rather than constantly, for example a fridge, depending upon how long the appliance is used for. This value is based upon a 28" Bang & Olufsen MS6000 used for 5 hours each day.

[23] This value is based upon the consumption of a laptop processor, as opposed to desktop machines that were considered for the other two scenarios, which have very efficient energy use.

[24] These are based upon the typical consumption of a gas cooker for the low efficiency and an efficient electric cooker for the high efficiency. BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community'.

The energy consumed by the lights within a dwelling will be dependent upon the wattage of the bulbs and the length of time the lights are switched on. To create an equation based on the bulb wattage, it is assumed that a light will be used for 6 hours per day; this is multiplied by the number of occupants to allow one bulb per person, for activities being carried out in different rooms in the dwelling.[25] If the mean bulb wattage is *x*, the energy consumption of the lighting can be determined in the following equation:

$$\text{Energy consumption (kWh.a}^{-1}) = (x \times \text{occupants} \times 6 \times 365.25) / 1{,}000$$

This can be used to demonstrate the significant difference between a dwelling that uses standard light fittings and one using compact fluorescent fittings. For example, five 100 W bulbs used for six hours per day would consume 1,095 kWh of electricity per annum; five 16 W compact fluorescent bulbs used for the same period would consume 175 kWh, a reduction of 84 percent. Clearly this could make a significant difference to the total annual energy consumption of the dwelling, and is a factor not taken into account in current energy consumption assessments.

Also, it was possible to improve the accuracy of the value of gains from lighting appliances, cooking and metabolic gains from the SAP methodology, which is based on the typical consumption as a factor of the floor area. If the appliance and lighting consumption is reduced through more efficient systems and appliances, it follows that gains will also be reduced by the same factor. Therefore a similar approach was adopted for the gains from lighting and appliances as for the consumption outlined above, based either on different efficiency scenarios, or a factor of the actual consumption.

The gains from the lights within the dwelling is considered to be equal to that of the consumption, as the vast majority of the energy output from lighting is as heat.[26] Therefore, the equation to determine the gains will be the same as that for the energy consumption; however, to determine this value in watts, to be compatible with the SAP worksheet, as opposed to kilowatt hours, the constant 8,760 is used to divide the annual wattage by the number of hours in a year.

$$\text{Gains (W)} = (x \times \text{occupants} \times 6 \times 365.25) / 8{,}760$$

[25] This assumption is based on lights being used between 18:00 and 0:00 hours. Precedents for these values are contained in Brenda and Robert Vale. Op. Cit. This constant could be varied if the value is anticipated to be different.
[26] This assumption has precedent in Brenda and Robert Vale. Op. Cit.

The actual metabolic gains are also calculated from the number of occupants, as opposed to being based on a factor of the floor area. The typical human will contribute 115 watts of heat,[27] which is multiplied by the occupancy level of the dwelling to produce a gains value in terms of kilowatt hours per annum. This value will vary with the degree of activity the inhabitant is undertaking,[28] and would be approximately 10 percent less for women and 45 percent less for children.[29] The value 115 was taken as a mean, but could be adjusted if required, such as, for example, a women's hostel or a children's home.[30] The annual gains would be dependent upon the period for which the dwelling is occupied; for an urban dwelling this may well differ from that of a suburban dwelling, due to higher levels of social inclusion for urban dwellers.[31] Assuming an occupancy period of 90 hours per week,[32] the metabolic gains per occupant can be determined in the following equation:

$$\text{Annual gains (kWh.a}^{-1}\text{)} = (\text{occupants} \times 115 \times 90 \times 52) / 1{,}000$$

To determine this value in watts, the annual gains are also divided by the number of hours in a year:

$$\text{Gains (W)} = (\text{occupants} \times 115 \times 90 \times 52) / 8{,}760$$

Both methodologies for determining the energy requirement for water heating, the consumption arising from lighting, appliances and cooking, and the incidental gains from lighting, appliances, cooking and metabolic gains will be included in the assessment tool. This creates a degree of flexibility in assessments. A more generalised energy consumption can be determined by using the method based on floor area, which will be quicker, where the specific data regarding water consumption and appliance and lighting specification or usage may not be known. A more detailed analysis can be undertaken using the specific details of lighting wattage, appliance specification, water consumption and the number of occupants in the dwelling. As the SAP methodology calculates the energy consumption in

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27 This value is based on a seated male at rest, but would increase with activity. CIBSE. *CIBSE Guide Volume A*, London: Chartered Institution of Building Services Engineers, 1986.

28 For example, when sleeping this value may be as low as 72 watts, when sitting 99 watts, undertaking light activity, such as cooking, be up to 140 watts, and medium activity, such as housework, 200 watts.

29 Brenda and Robert Vale. Op. Cit.

30 Even the gains from pets could be included, with the typical dog contributing 53 watts of heat, cat 15 watts, rabbit 11 watts, and hamster 2 watts CIBSE. Op. Cit.

31 An introspective lifestyle prevalent in suburban housing, linked to the increasing numbers of divorced single males isolated from sources of social interaction, has been attributed to causing an increase in suicide rates in this section of the population.

32 This is based on 12 hours per day for 6 days (say 19:00 to 07:00) and 18 hours for 1 day, or 54 percent of the year. This provides a base value that can be varied if the occupancy period is

terms of GJ per annum, the consumption value, as well as any respective constants in the worksheet, is converted into kWh.[33]

The total energy consumption of the dwelling per annum is then divided by the floor area of the dwelling, to arrive at the benchmark of Energy Consumption: Inhabitation, in terms of $kWh.m^{-2}.a^{-1}$.

9.9 Energy Generation: Inhabitation

Energy generated from renewable sources can then be determined. Steps to calculate the quantity of energy generated by photovoltaic panels, solar water heaters and wind turbines are included within the worksheet.

This criterion is a measure of the quantity of energy that is generated by the dwelling. This may be a proportion of, match, or exceed the energy consumption of the dwelling. The SAP methodology already takes account of incidental gains, which include passive solar, metabolic and gains from lighting and domestic appliances, and the contribution made to water heating by solar water panels. Because the former are incidental gains, these are left within the worksheet as they exist in the SAP methodology. As solar water panels are a specific renewable energy source, the steps to determine the level of contribution are moved to be under the heading of energy generation.

The SAP method does not take into account the orientation of the panels. The presumption is made that common sense will dictate that panels are located on a southerly aspect;[34] the *CIBSE Guide* contains data on the range of solar irradiation for orientations between southeast and southwest to determine solar collector performance. The data shows that the maximum decrease in the direct irradiation level moving from south orientation to southeast or southwest is 11 percent, which is for vertical surfaces; the value decreases for inclines

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considered to be different. This may be the case for different dwelling types, such as housing for the elderly or flats in hostels.

[33] 1 kWh = 3.6 MJ

[34] The calculation is based on measurements from a horizontal panel. It is considered that the value will vary little for angled panels, and those varying from a due south orientation so long as they are facing between south east and south west, in comparison to other variables, such as the efficiency of the specific panel. Personal communication, Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.

less than vertical, down to zero decrease in the horizontal plane.[35] Although at first impression this may appear significantly high, an 11 percent decrease equals a reduction of only 0.11 $kWh.m^{-2}$. Therefore, provided that the orientation of panels is between southeast and southwest, the orientation is considered to be of relatively negligible consequence.

The Energy Generation: Inhabitation section is expanded to include steps to determine the contribution that could be made by photovoltaic panels. In terms of orientation between southeast and southwest, the same assumption of negligible consequence is made. The CIBSE data referred to above can also be used to determine the impact of the incline angle of the photovoltaics. The maximum direct solar irradiation level is for a plane at 45 degrees to the horizontal. For planes of 30 and 60 degree inclines with a southerly orientation, the decrease in irradiation is 2 and 4 percent respectively; for planes of 30 and 60 degree inclines with a southeasterly or southwesterly orientation, the decrease in irradiation is 2 and 7 percent respectively.[36] Therefore, provided that the angle of the photovoltaics is between 30 and 60 degrees to the horizontal, the incline will also be of relatively negligible consequence.

The energy that is available from photovoltaic panels will depend 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 is provided 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 $kWh.m^{-2}.a^{-1}$. 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;[37] 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.

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[35] CIBSE. Op. Cit. The actual variations are: zero for horizontal planes, 8 percent for planes at 30 and 45 degrees (0.11 $kWh.m^{-2}$), 10 percent for planes at 60 degrees (0.13 $kWh.m^{-2}$), and 11 percent for vertical planes (0.11 $kWh.m^{-2}$).

[36] CIBSE. Op. Cit. The actual variations are: 2 percent for south, southeast and southwest facing planes at 30 degrees (0.03 $kWh.m^{-2}$), 4 percent for south facing planes at 60 degrees (0.06 $kWh.m^{-2}$), and 7 percent for southeast and southwest facing planes at 60 degrees (0.09 $kWh.m^{-2}$).

Steps are also included to determine the contribution that could be made by wind turbines.[38] This particularised through meteorological data for the average monthly wind velocity at the location of the turbine. As this data is typically taken at a height of 10 metres, the value is then amended to account for the difference between the velocity at 10 metres and the velocity at the hub height of the turbine, which is 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. A further step is also included to account for a contribution made by other sources beyond those given above.

9.10 CO_2 Emissions: Inhabitation

Details of the fuel types, energy consumed during inhabitation and emission factors are used to calculate the consequent CO_2 emissions. Both gross and net values are determined, the latter taking account of energy generated by renewable sources.

With the energy consumption of the dwelling and the contribution made by renewable energy generation determined the CO_2 emissions arising from that energy consumption is calculated. The first step determines the emissions arising from each component of consumption within the dwelling, such as space heating, water heating and cooking. This is because if different fuel sources are used, then there will be different emission factors.

$$CO_2 \text{ emissions} = \text{fuel consumption x emission factor}$$

The tool will identify both gross and net CO_2 emissions. The gross value is the level of emissions that will occur if any of the available energy generation technologies are not taken into account, for example the effective CO_2 emissions that would be created at night or other times when photovoltaic panels are not functioning. This will allow the designer to determine what energy generation technologies are appropriate, on balance with the additional embodied energy and embodied CO_2, after the weightings account for their relative significance.

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

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

Where the energy consumption is met by CO_2-free renewable sources, the emission factor will be zero; if a proportion of the energy demand is met by such sources, then the value of the energy consumption will be reduced by that quantity before the emission level is determined. Evidently, if the renewable sources exceed the level of consumption, this will lead to a negative level of net emissions; provided that the excess energy is stored or, more likely, fed into the mains distribution network; this is considered acceptable, as it will be preventing pollution arising from consumption elsewhere.

The CO_2 emissions arising as a consequence of the potable water consumption is then calculated using the benchmark of consumption determined earlier, to quantify the interconnection, which is multiplied by a constant.[39] As green spaces absorb CO_2, the assimilation capacity of the green spaces of the dwelling is then calculated, by multiplying the area of green space by a constant.[40]

The net value of CO_2 emissions per annum is then determined by adding the emissions arising from the energy consumption within the dwelling and the consequent emissions from the potable water consumption, and then subtracting the reduction from renewable energy generation and the CO_2 assimilated by the green space. To determine the benchmark of CO_2 Emissions: Inhabitation, in terms of $kgCO_2.m^{-2}.a^{-1}$, this value is than divided by the floor area of the dwelling.

9.11 Pollutant Emissions during Inhabitation

Details of the fuel types, proportion of each type used to supply the energy consumed during inhabitation and relevant emission factors are used to calculate the pollution emissions per kilowatt hour. Again both gross and net values are determined, the latter taking account of energy generated by renewable sources.

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[39] Shouler, M. C. and J. Hall. *Water Conservation*, Garston: Building Research Establishment, November 1998. This constant, of 0.33, is based on the level of CO_2 emissions arising as a consequence of the energy used to supply the dwelling with potable mains water, which is 0.33 $kgCO_2.a^{-1}$ per litre per day. Please refer to Annexe 3.37, Water Consumption: Inhabitation, in Volume 3.

[40] Wackernagel, M. and W. Rees. *Our Ecological Footprint*, Canada: New Society Publishers, 1996. The most effective assimilators of CO_2 in terms of green space, which are forests, accumulate 1.8 tonnes of carbon per hectare. 1.8 tonnes of carbon per hectare is the equivalent of 0.18 $kgC.m^{-2}$. From the relative atomic mass, 1 kgC is the equivalent of 0.66 $kgCO_2$. Therefore, the assimilation potential for green space is 0.66 $kgCO_2.m^{-2}$.

The value of this benchmark is dependent upon the proportions of fuel types that make up the overall fuel consumption of the dwelling during inhabitation. It is measured on the basis of the pollution created by the relative quantity of each fuel that would account for 1 $kWh.m^{-2}.a^{-1}$ of the dwelling's overall energy consumption. For example, if the Energy Consumption: Inhabitation benchmark is 25 $kWh.m^{-2}.a^{-1}$, and 10 $kWh.m^{-2}.a^{-1}$ of this is electricity and 15 $kWh.m^{-2}.a^{-1}$ gas, then of each 1 $kWh.m^{-2}.a^{-1}$, 0.4 $kWh.m^{-2}.a^{-1}$ will be electricity and 0.6 $kWh.m^{-2}.a^{-1}$ gas.

This proportion is determined by adding each component of the dwelling's overall energy consumption by its fuel type, such as electricity, gas or coal, and dividing that value by the floor area of the dwelling. These values, now in terms of $kWh.m^{-2}.a^{-1}$ for each fuel type, can be divided by the overall energy consumption benchmark, to determine their relative proportion of the total consumption. The electricity value has the energy that is generated from non-polluting renewable sources deducted before the proportion is calculated, so that only the electricity that is provided by the mains grid is used to determine the pollution emissions. The equation for this calculation is given below:

$x =$ ((electricity consumption / floor area) – generated electricity)

Proportion of total consumption = x / Energy Consumption: Inhabitation

Now that the proportion of each fuel of the total energy consumption has been determined, this value is multiplied by the relevant emission factors.[41] The total, which is the Pollutant Emissions during Inhabitation benchmark, is determined by summing the emissions from each fuel type:

$x =$ Proportion of total consumption, gas x emission factor (0.879)

$y =$ Proportion of total consumption, electricity x emission factor (6.494)

Pollutant Emissions during Inhabitation = $x + y$

[41] These are given as tabulated data for each fuel type that the dwelling is likely to consume. The are derived from figures from the National Atmospheric Emissions Inventory in, Howard, Nigel, Suzy Edwards and Jane Anderson. *Methodology for Environmental Profiles of Construction Materials, Components and Buildings*, London: Construction Research Communications Ltd., 1999. The values are adjusted to account for the upstream and combustion emission factors, and the relative primary to delivered efficiency ratios. The worksheet procedure itself will take account of the relative efficiencies

9.12 Design Life Span

The design life span is a target benchmark. It is used in conjunction with the life expectancy of the materials used to construct the dwelling to determine how many times they will have to be replaced within the projected life span of the dwelling; this informs the embodied energy calculation, accounting for lifecycle maintenance. The benchmark is also used in the lifecycle energy and water cost analysis.

The design life span benchmark will have an impact in terms of maintenance and replacement of the fabric of the dwelling. If the life span of the dwelling is such that materials, such as the roof covering, reach the end of their natural life and have to be replaced, this will have to be accounted for in terms of the overall embodied energy of the dwelling. Dividing the mean life span of the material[42] by the design life span benchmark of the dwelling, will provide a 'replacement ratio' for materials that are to be replaced during the life span of the 'urban house in paradise'. If this value is greater than one, then the material will most likely to have to be replaced during the life span of the dwelling; this replacement ratio will then be used in the embodied energy calculation. The additional embodied energy required in maintenance, in the material replacement of components throughout the lifecycle of the dwelling, can therefore be accounted for.

The design life span benchmark is also used in the lifecycle energy and water consumption analysis of the dwelling. The embodied energy of the dwelling is converted into an annual equivalent value by dividing it with the life span benchmark; this provides a value that can be compared directly with the annual energy consumption to determine the balance between embodied and inhabitation energy consumption. The same process is conducted for CO_2 emissions. This is a reversal of the methodology used in the Building Research Establishment's *Envest* assessment, which multiplies the annual energy consumption by the life span and adds this value to the embodied energy. The consequence of the latter is to create a better overall rating for the building by reducing its life span, which does not make the most efficient use of materials and energy embodied in the building's fabric. By using the methodology proposed for the 'urban house in paradise' assessment tool, maximising

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of the heating systems. For a breakdown of these emission factors, please refer to Annexe 3.23, Pollution: Energy Consumption during Inhabitation, in volume 3.

[42] The life span of the materials will be based on data in the Research Steering Group of the Building Surveyors Division and the Building Research Establishment's *Life Expectancies of Building Components*, London: Royal Institute of Chartered Surveyors, August 1992.

the life span of the dwelling will be encouraged, therefore maximising the efficient use of materials and energy embodied within it.

9.13 Ecological Weight: Embodied Energy

To calculate the embodied energy of the whole dwelling, firstly the volume of materials is determined; links created from the thermal performance calculations, using the thickness of materials, are utilised here. Standard values for density and embodied energy per unit mass convert the volume of each element into its embodied energy.

The level of embodied energy is dependent upon the quantity of those materials used to construct the dwelling. Therefore, in order to determine the Ecological Weight: Embodied Energy benchmark, the tool will first have to determine the quantity of material used to construct the dwelling. Determining the level embodied energy through the quantity of material has precedent. In the development of *Envest*, to compare the environmental profiles of different wall construction for office buildings the BRE use the method of determining the quantity of material, quantified in terms of its mass, in a given area of the element for different construction methods.[43] The shortcoming of basing the quantity of material on a unit area of typical construction, rather than the actual quantity of material in the building itself, has already been identified. That using material mass is a valid methodology for determining the embodied energy of the dwelling is borne out by other precedents.[44]

The initial quantification of material is determined in terms of volume. It is more convenient to consider a given dwelling design in this way, rather than attempting to assess the mass directly. To make this process more straightforward the dwelling is broken down into principal elements: roof, walls, internal floors, ground floor and foundations. Because the

[43] Personal communication with Building Research Establishment's Centre for Sustainable Construction, 22 March 2000.

[44] Smith et al. use the total mass of building materials to compare the embodied energy in a standard and a low energy dwelling; Smith, Matthew, John Whitelegg and Nick Williams. 'Life Cycle Analysis of Housing', *Housing Studies*, Volume 12, Number 2, 1997. Fay et al. and Treloar et al. also both adopt the methodology of quantifying the building materials in the dwelling, and converting this value, here in terms of volume, into the total embodied energy through standard values of embodied energy; Fay, Roger, Graham Treloar and Usha Iyer-Raniga. 'Life Cycle Energy Analysis of Buildings: A Case Study', *Building Research & Information*, Volume 28, Number 1, 2000, and Treloar, G., R. Fay, P. E.

standard values of embodied energy, which are used next to determine the embodied energy of that quantity of material, are based on kWh per unit mass, once the volume of materials is determined this is converted into its mass by using a table of standard densities. The mass of each material is then multiplied by the standard value of its embodied energy. The total embodied energy in the dwelling is determined by adding the values for each element of the dwelling; this is converted into the Ecological Weight: Embodied Energy benchmark by dividing the total value by the dwelling's floor area. Therefore, where the thesis moves beyond the *Envest* model is that the embodied energy is based on the actual quantity of material in the building, rather than on the average quantity of material in one square metre of the selected construction technology multiplied across the area of each element.

It is the intention to create the tool so that it can assess the majority of construction technologies and methods, such as masonry and timber frame. However, there is a dichotomy present between achieving a sufficiently robust method of assessment, which can accommodate a variety of construction technologies, and the tool being of a manageable size. Therefore, in the event that the methodology for determining the volume of material is not appropriate to the dwelling being assessed there is an opportunity to input a value for the volume of the materials being considered.

For skins, such as walls, the volume of material is determined by multiplying the area of the material, derived from the perimeter and wall height values entered at the dimensional information steps, by its thickness. Using the thickness as an identified value facilitates linking the benchmark into others where there is a consequential effect to varying the material's width; an example of which is insulation. When determining the Thermal Performance benchmark, the worksheet requires that the thickness of the insulation be entered into a box; this value is then used in determining the energy consumption of the dwelling. By using the insulation thickness from that step in the embodied energy calculation, as well as the Other Greenhouse Gas Emissions steps, the consequential effects of varying the insulation thickness on the Energy Consumption: Inhabitation, Ecological Weight: Embodied Energy, Other Greenhouse Gas Emissions and Thermal Performance benchmarks can be interrelated to each other.

D. Love and U. Iyer-Rangia. ' Analysing the Life Cycle Energy of an Australian Residential Building and its Householders', *Building Research & Information*, Volume 28, Number 3, 2000.

9.14 Ecological Weight: Embodied CO_2

The CO_2 emissions embodied in the dwelling are dependent upon the level of embodied energy, the mix of fuel types used to supply that energy, and their emission factors. These three factors are used to determine the benchmark.

As with CO_2 Emissions: Inhabitation, the level of emissions arising from the energy embodied in the dwelling will be dependent upon the fuels consumed in supplying that energy, as different fuels produce different levels of CO_2 per kilowatt hour; it is quantified by the mix of fuels used. Therefore the first step in calculating this value is to determine the ratio of different fuels consumed. However, an inherent difficulty exists in establishing this; although the data for the ratio of fuels used in the production of different building materials and components does exist, it is held on a confidential database belonging to the Building Research Establishment.[45]

To facilitate the potential to use such data, the worksheet contains the steps required to vary the ratio of fuel types, accounting for the benefit of specifying materials and components that use fuels with a lower carbon dioxide emission content in their production. However as the details of such ratios are not available at present, a default value of one third electricity, one third gas and one third petroleum is assumed.

9.15 Other Greenhouse Gas Emissions

HCFC emissions can occur through the use of foam insulation. The volume of insulation used in the dwelling is derived in the embodied energy calculations; this value is multiplied by the emissions factor of the quantity of blowing agent lost in the production of the insulation to determine the level of emissions.

The primary source of greenhouse gas emissions, other than the burning of fossil fuels, associated with the lifecycle of a dwelling is in the production of some foam insulation materials, where the blowing agent is a gas which contributes to the greenhouse effect, such as Chlorofluorocarbons (CFCs) and Hydrochloroflourocarbons (HCFCs). Therefore

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

this value is calculated using an interrelated link to volume of insulation value determined in the embodied energy calculations.

The volume of insulation, determined in the embodied energy calculations and therefore creating an interrelated link, is multiplied by the emission factor of the quantity of blowing agent lost in the production of the insulation. The only emission factor that has been able to be determined is for HCFC blown foam insulation; this is derived from two sources. Firstly from a manufacturer who provided the value of HCFC content in the insulation, of 3.44 $kgHCFC.m^{-3}$.[46] The second was a value for the quantity of HCFC that is lost into the atmosphere during the production processes; this is the value of HCFC emissions, as during the life span and upon demolition none is lost. The mean value for loss is 3.5 percent of the added blowing agent.[47] Therefore, the emission factor will be 3.5 percent of 3.44 $kgHCFC.m^{-3}$, or 0.12 $kgHCFC.m^{-3}$.

9.16 Scoring Against the Benchmarks

The performance of a dwelling being assessed against the benchmarks is presented in two formats. A profile of values for each of the eleven criteria's benchmark is given. An overall score, using the weightings previously determined to account for the relative significance of the criteria, is then derived; varying the values entered to maximise this score will produce the most ecologically sustainable balance of performance between the criteria.

When the tool is applied to a dwelling being assessed against the benchmarks of the 'urban house in paradise', a value will be derived for its performance against each of the criteria. As has been demonstrated by the process of prioritising the criteria, in terms of the overall contribution to reduction ecological impact some criteria are more significant than others are. For example because the Energy Consumption: Inhabitation criterion is much more significant than Ecological Weight: Embodied Energy, achieving the benchmark of Energy Consumption: Inhabitation will have more benefit in improving of ecological sustainability than achieving that of the Ecological Weight: Embodied Energy. Also, there may be instances where achieving one benchmark may preclude achieving another; this is where the assessment tool can assist in determining the best overall balance of priorities. The

[46] Personal communication, Mr J. Bullen, Technical Sales, Isothane, 8 December 1999.

significance value of each of the criteria, derived during the prioritising in chapter 7.0, can be used to establish if achieving, or exceeding, one benchmark at the expense of another is of more benefit to the overall ecological sustainability of the project.

Therefore, the scoring by the assessment tool is based upon determining a percentage for each of the criteria of the dwelling being assessed, as a factor of the benchmarks of the 'urban house in paradise'. This percentage is then multiplied by the weighting determined for that criterion, to take account of the relative significance of each. A total score is then determined by summing the scores for each of the criteria, and converting this to a percentage of the overall score of the 'urban house in paradise'.

For criteria where there are several components, for example Thermal Performance which includes benchmarks for roof, wall, ground floor, glazing and external doors, the weighting will need to be broken down proportionally between each component. For Thermal Performance, as an example, the area of each element is determined as a percentage of the whole envelope area of the dwelling; the weighting given to each element is then a percentage of the total weighting determined for the Thermal Performance criterion. For example, if the total wall area, excluding openings, is 50 percent of the total envelope area, its weighting will be 50 percent of the total weighting allocated to Thermal Performance, i.e. 50 percent of 0.054. This will, therefore, account for the relative proportion of each element in terms of the overall envelope area of the dwelling, and attribute a rating accordingly.

9.17 Relative Embodied and Inhabitation Energy Consumption and CO_2 Emissions

The energy embodied within and consumed by the dwelling during inhabitation is used, in combination with the life span benchmark, to determine the relative proportion of each in the lifecycle energy consumption of the dwelling. This demonstrates their relative significance, and how that varies as the design life span varies.

The final steps in the worksheet create a comparison between the quantity of embodied energy in the dwelling and the quantity of energy consumed during inhabitation, and also

[47] Personal communication, Mr G. W. Ball, British Rigid Urethane Foam Manufacturers' Association, 25 April 2000.

between the quantity of embodied CO_2 and the quantity of CO_2 emitted during inhabitation. Because the weightings used during the scoring are relative, these steps will provide an absolute quantification of the balance between the amount energy, and consequent emissions, used to create the dwelling, and the amount that it consumes during its life span.[48]

The comparison is made by way of the life span benchmark; this will allow one to perceive how altering the length of the design life span of the dwelling will affect the efficiency of the energy consumption, and consequent CO_2 emissions, that are embodied within it. To arrive at comparable units of measurement, either the embodied energy ($kWh.m^{-2}$) could be divided by the life span, or alternatively, the level of energy consumption during inhabitation ($kWh.m^{-2}.a^{-1}$) could be multiplied by the life span. As described above, the decision was taken that in deriving comparable units between embodied and annual consumption to use the former method, rather than the approach used by *Envest* of the latter. This was to encourage maximising the longevity of the dwelling, and therefore the efficient use of the materials and energy embodied within it.

9.18 Relative Contribution of Elements to Total Embodied Energy, Total Energy Consumption: Inhabitation and Total CO_2 Emissions: Inhabitation.

The energy embodied within and consumed by the dwelling is broken down into its contributory components to identify where the greatest source of consumption is, to allow the opportunity for it to be reduced.

The total energy consumption and the total embodied energy consumption is broken down into its constituent components for each: space heating, water heating, pumps and fans, lights and appliance and cooking for energy consumption during inhabitation, and foundations, basement, ground floor, frame, external walls, roof, windows and roof lights, and internal floors for the embodied energy. This serves as a way in which to identify the greatest contributors to the overall embodied and inhabitation energy consumption, and therefore to allow the user the opportunity to reduce the most significant, in order to achieve better performance.

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[48] These steps were considered to be important, as they create an absolute, rather than relative,

9.19 Lifecycle Energy and Water Costs

The lifecycle energy and water costs of the dwelling are included as they may provide an incentive for achieving higher standards of performance against the criteria, by demonstrating the lifecycle cost savings that could result.

Although these were not included within the prioritised criteria, as the spreadsheet algorithms have already been developed to ascertain the benchmark values, it was a straightforward process to incorporate them into the spreadsheet for the tool, and therefore they have been included. A reason for this to be appropriate, whilst the Lifecycle Cost benchmark was one of the lowest in the prioritised hierarchy, is that the significant reductions achievable in lifecycle energy and water costs might act as an incentive to adopt the benchmarks of the 'urban house in paradise' into wider practice. The assessment tool could therefore be used as a mechanism to demonstrate the potential cost reductions, through reduced energy and water consumption, that can be achieved by creating more ecologically sustainable dwellings.

The process for determining lifecycle costs was derived during the process of benchmarking the criteria of the 'urban house in paradise'. In summary the equations are given below. The constant of 1.02 is used to account for the annual increase in fuel and water costs;[49] this value can be changed if appropriate.

Lifecycle energy cost =

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

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

---

comparison between six of the eleven most significant criteria that are being assessed by the tool.

49 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.

Lifecycle water cost =

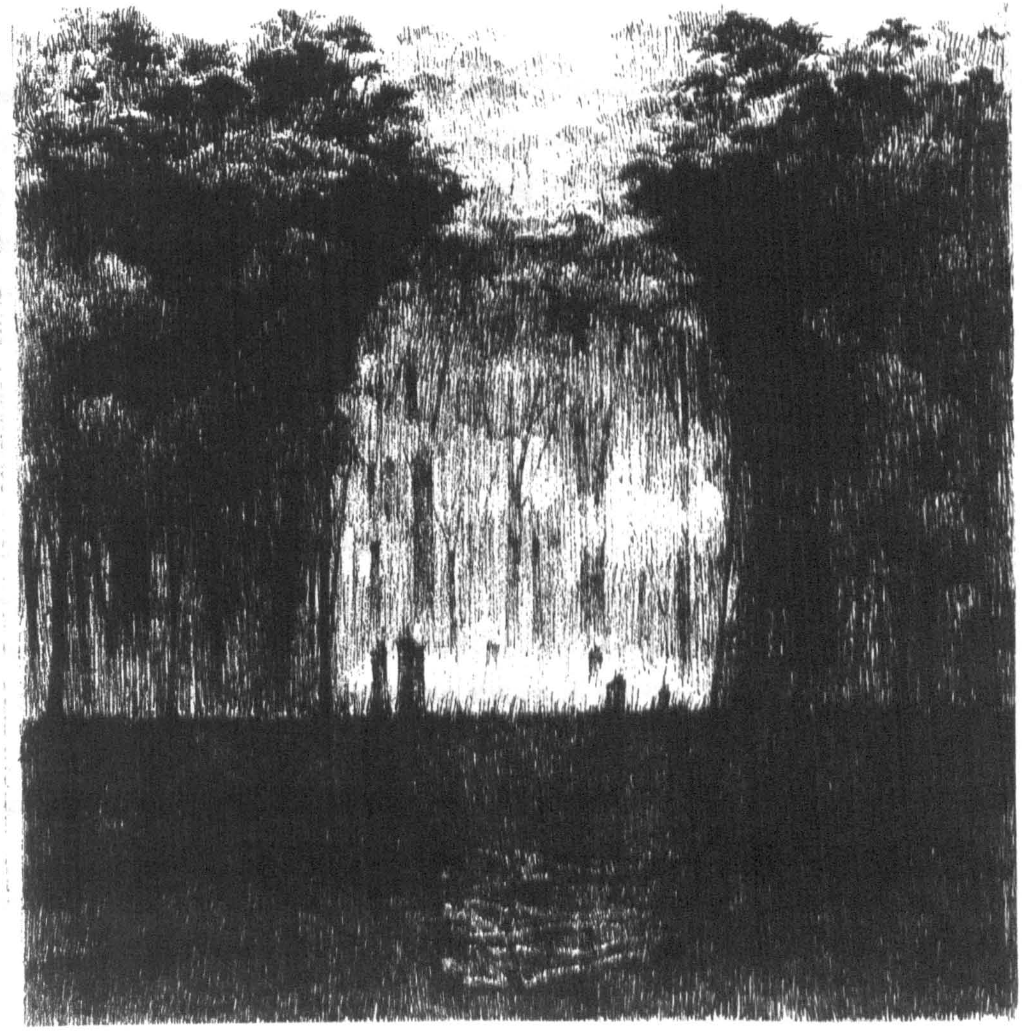
$$y = \sum_{n-1}^{0} (x + v + z) \cdot 1.02^{n}$$

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

With the methodology for assessing a design for a dwelling against the benchmarks of the 'urban house in paradise' developed, and the hierarchy and interrelated links between criteria determined, it was possible to formulate that assessment process into a worksheet. This would provide a standard approach to assessing a dwelling, in order to achieve consistency in the values of the benchmarks that arise from it.

The Urban House in Paradise

Chapter 10



The ‘Urban House in Paradise’ Assessment Tool

10.0 The 'Urban House in Paradise' Assessment Tool

With the methodology of calculating the most significant eleven benchmarks established it was possible to develop the assessment protocol as a tool that would enable an architect to assess the performance of a dwelling, in terms of the benchmarks of the 'urban house in paradise', at the design stage. This was in the format of a worksheet, based upon the initial foundation of the SAP assessment. The interrelated links that have been identified between the criteria were then used as a framework through which to structure the creation of the assessment tool

10.1 Assessment Tool in Worksheet Format

With the protocol for assessing of each of the criteria determined the worksheet could be developed, creating a step by step methodology for evaluating the performance of a dwelling against the benchmarks. The basic structure for this was the SAP worksheet. Numbering each step enabled values and outcomes to be used elsewhere in the worksheet, creating the interrelated links between criteria.

The following pages present the 'urban house in paradise' assessment tool in its worksheet format. The structure of the worksheet is based upon a numbered series of steps, each of which requires a piece of data to be entered or a calculation. The steps are numbered so that where the data or the outcome of the calculation is required in subsequent steps, it can be referenced. This is a comparable format to that of the SAP assessment, the initial foundation from which the worksheet has been constructed. The worksheet presents all of the algorithms, which can then used to construct a computer spreadsheet version of the assessment.

The numbering of each step helps to create the interrelated linkages between different criteria, so that if one value is varied the impact of that variation can be followed through the sequence of calculations to determine its impact on other benchmarks in the assessment. This can be demonstrated through a scenario commencing with wall insulation. At step 65 the thickness of the wall insulation is entered. This value is used in the steps that follow to determine the U-value of the wall to quantify its thermal performance benchmark; however, the value is also used to continue the Energy Consumption: Inhabitation benchmark, and in turn, depending upon the fuel emission factor, the consequent CO_2 Emission: Inhabitation benchmark. The insulation thickness in the wall is also carried into the Ecological Weight: Embodied Energy analysis, at steps 420 and 439, depending upon the construction technology, and then consequent CO_2 emissions. This shows how the impact of altering just one value can be traced through the worksheet to determine its effect on a number of the benchmarks, both positively and negatively. That altering one value can impact upon at least six of the twelve benchmarks that the worksheet measures exemplifies the importance of creating the interrelation within the assessment.

In places there are two methodologies for calculating a particular value. An example of this is the energy consumption of lights and appliances; a broadbrush value can be determined using a value based on the total floor area of the dwelling, which has been adapted and expanded upon from the BREDEM model, or alternatively a more specific value can be determined on the basis of the wattage of lighting and appliances that are to be fitted in the dwelling. This allows that assessment to be tailored for dwellings with very efficient appliances. The user can choose the appropriate methodology on the basis of information available or thoroughness of assessment.

Dimensional Information

Ground floor:	Area = ______ 1 x ceiling height = Volume	= ______	2
First floor:	Area = ______ 3 x ceiling height = Volume	= ______	4
Second floor:	Area = ______ 5 x ceiling height = Volume	= ______	6
Subsequent:	Area = ______ 7 x ceiling height = Volume	= ______	8
Total floor area:	1 + 3 + 5 + 7	= ______	9
Total volume:	2 + 4 + 6 + 8	= ______	10
Number of storeys:		= ______	11
Dwelling perimeter (measured to centreline of walls):		= ______	12
Building height (measured to mean wall height):		= ______	13
Designed occupancy level (number of bed spaces):		= ______	14
Space standards - Area ($m^2.p^{-1}$):	9 / 14	= ______	15
Space standards - Volume ($m^3.p^{-1}$):	10 / 14	= ______	16

Ventilation

Number of chimneys:	______ x 40	= ______	17
Number of flues:	______ x 20	= ______	18
Number of fans and passive vents:	______ x 10	= ______	19
Infiltration from chimneys, flues and fans:	(17 + 18 + 19) / 10	= ______	20
Air Tightness: *Enter air tightness target ($ac.hr^{-1}$ at 50 Pa)*		= ______	21

Refer to table A for comparable air tightness targets.

Total Infiltration:	(21 / 20) + 20	= ______	22
Number of sheltered sides:		= ______	23
Shelter factor:	1 – (0.075 x 23)	= ______	24
If mechanical ventilation with heat recovery:			
effective air change rate:	(22 x 24) + 0.17	= ______	25
Note: If no heat recovery, add 0.33 $ac.h^{-1}$ to 25			
If natural ventilation, air change rate:[1]	22 x 24	= ______	26
If 22 x 24 <1, 26 =	$0.45 + ((22 \times 24)^2 \times 0.45)$		
Ventilation rate:	25 or 26	= ______	27

[1] In the SAP worksheet, the constant 0.5 is used in the event that step 26 is less than 1. This is to ensure that the minimum ventilation rate used in the assessment is 0.5 $ac.h^{-1}$; if the envelope is very airtight in a naturally ventilated dwelling, then it is assumed that the inhabitants will periodically open windows to achieve the desired influx of fresh air; personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000. This constant's value has been revised to 0.45 $ac.h^{-1}$ following the analysis in the Quality of the Internal Environment: Ventilation and Air Tightness benchmark for the minimum ventilation rate of the dwelling.

U Values

If using design U-value benchmarks, go to step 56, 81 and 106 and insert design value as appropriate. For surface resistances, refer to table B. For values of thermal conductivity of common building materials, refer to table C.

U-Roof:

Breakdown of elements, as appropriate

Outer finish: material-	thickness (m) = ____	28	conductivity (λ)	= ____	29
Waterproof layer: material-	thickness (m) = ____	30	conductivity (λ)	= ____	31
Sheathing: material-	thickness (m) = ____	32	conductivity (λ)	= ____	33
Outer structural: material-	thickness (m) = ____	34	conductivity (λ)	= ____	35
Insulation: material-	thickness (m) = ____	36	conductivity (λ)	= ____	37
Inner structural: material-	thickness (m) = ____	38	conductivity (λ)	= ____	39
Internal finish: material-	thickness (m) = ____	40	conductivity (λ)	= ____	41

Note: *If insulation is in one plane and not the other, discount the inappropriate value in the following steps*

R_A, *for solid roof construction*:

R_A(solid):	R_{so} + (28 / 29) + (30 / 31) + (32 / 33) + (34 / 35) + (36 / 37)	= ____	42

R_A, *for timber roof construction, with insulation laid between joists*:

Fractional area of joists:	joist width / joist centre spacing	= ____	43
Fractional area of insulation:	1 – 43	= ____	44
Resistance through timber (R_{tim}):	R_{so} + (28 / 29) + (30 / 31) + (32 / 33) + (34 / 35)	= ____	45
Resistance through insulation (R_{ins}):	R_{so} + (28 / 29) + (30/ 31) + (32 / 33) + (36 / 37)	= ____	46
R_A(timber):	1 / ((43 / 45) + (44 / 46))	= ____	47
R_A:	either 42 or 47	= ____	48

R_B, for solid roof construction:

R_B(solid):	(36 / 37) + (38 / 39) + (40 / 41) + R_{si}	= ____	49

R_b, *for timber roof construction, with insulation laid between joists*:

Fractional area of joists:	joist width / joist centre spacing	= ____	50
Fractional area of insulation:	1 – 50	= ____	51
Resistance through timber (R_{tim}):	(38 / 39) + (40 / 41) + R_{si}	= ____	52
Resistance through insulation (R_{ins}):	(36 / 37) + (40 / 41) + R_{si}	= ____	53
R_B (timber):	1 / ((50 / 52) + (51 / 53))	= ____	54
R_B:	either 49 or 54	= ____	55
Angle of roof plane (θ):		= ____	56

Rt:	48 x cos 56 + R_{cav} + 55	= ______	57
U_{roof}:	1 / 57	= ______	58

U-Wall:

Breakdown of elements, as appropriate:

Outer finish: material-	thickness (m) = ______	59	conductivity (λ)	= ______	60
Outer leaf: material-	thickness (m) = ______	61	conductivity (λ)	= ______	62
Sheathing: material-	thickness (m) = ______	63	conductivity (λ)	= ______	64
Insulation: material-	thickness (m) = ______	65	conductivity (λ)	= ______	66
Inner leaf: material-	thickness (m) = ______	67	conductivity (λ)	= ______	68
Internal finish: material-	thickness (m) = ______	69	conductivity (λ)	= ______	70

For solid and masonry walls:

Sum of resistances (Rt) =	R_{so} + (59 / 60) + … + (69 / 70) + R_{cav} + R_{si}	= ______	71
U_{Wall} =	1 / 71	= ______	72

For timber frame:

Inner leaf

Fractional area of studs:	stud width / stud centre spacing	= ______	73
Fractional area of insulation:	1 - 73	= ______	74
Resistance through timber (R_{tim}):	(0.5 x R_{cav}) + (63 / 64) + (67 / 68) + (69 / 70) + R_{si}	= ______	75
Resistance through insulation (R_{ins}):	(0.5 x R_{cav}) + (63 / 64) + (65 / 66) + (69 / 70) + R_{si}	= ______	76
R_{inner}:	1 / ((73 / 75) + (74 / 76))	= ______	77

Outer leaf

R_{outer}:	R_{so} + (59 / 60) + (61 / 62) + (0.5 x R_{cav})	= ______	78
Rt:	77 + 78	= ______	79
U_{wall}:	1 / 79	= ______	80
U_{wall}:	72 or 80	= ______	81

U-Ground floor:

Joist/beam: material -	depth (m) = ______	82	conductivity (λ)	= ______	83
Deck: material -	thickness (m) = ______	84	conductivity (λ)	= ______	85
Insulation: material -	thickness (m) = ______	86	conductivity (λ)	= ______	87

External wall thickness:	= ______	88
Thermal conductivity of earth: (Standard value = 1.4 $W.m^{-1}.K^{-1}$)	= ______	89
Floor length (greater dimension):	= ______	90
Floor breadth (lesser dimension):	= ______	91

The following methodology is based on four exposed walls.

For floors with two parallel edges exposed, the methodology is followed for a floor the appropriate breadth but of infinite length (see step 93). For floors with two edges at right angles exposed, the U-value is the same as for floors of twice the length and twice the breadth with four edges exposed. For floors with a *single exposed edge, the U-value is the same as for floors with two parallel edges exposed but of twice the breadth (see step 93).*

For floors in contact with the ground:

Floor length / breadth:	90 / 91	= ______	92
	(2 x 89 x β) / (0.5 x 91 x π)	= ______	93
Refer to table D and 92 for β			
	(0.5 x 89) / ((0.5 x 91) + (0.5 x 90))	= ______	94
	93 x artanh 94	= ______	95
Accounting for insulation:	(1 / 95) + (86 / 87)	= ______	96
$U_{non\text{-}suspended\ floor}$:	1 / 96	= ______	97

For suspended floors:

Fractional area of joists/beams:	joist width / joist centre spacing	= ______	98
Fractional area of skin:	1 – 98	= ______	99
Resistance through joist/beam ($R_{j/b}$):	(82 / 83) + (84 / 85) + (86 / 87)	= ______	100
Resistance through deck (R_{deck}):	(84 / 85) + (86 / 87)	= ______	101
Resistance of floor slab:	1 / ((98 / 100) + (99 / 101))	= ______	102
Resistance of earth (R_e):	$(1 / U_g) - R_{si}$	= ______	103
Note: Where U_g = steps 88 to 97, for 4 exposed edges.			
Ventilation resistance:	0.63 x 91	= ______	104
	$((1 / (0.09 + 103)) + (1 / (0.29 + 104)))^{-1}$	= ______	105
R_t:	R_{si} + 0.09 + 102 + 105	= ______	106
$U_{suspended\ floor}$:	1 / 106	= ______	107
U_{floor}:	either 97 or 107	= ______	108

Windows:	Independently certified manufacturer's U-value	= ______	109
Doors:	Independently certified manufacturer's U-value	= ______	110

The Dwelling Envelope

Roof area (excluding openings):		= ______	111
External wall area (excluding openings):		= ______	112
Party wall area:		= ______	113
Ground floor area:	1	= ______	114
Window area:		= ______	115
Roof light area:		= ______	116
External door area:		= ______	117
Other element(s):		= ______	118

Total area of dwelling envelope:	111 + 112 + … + 117 + 118	= ______	119

Heat Losses and Heat Loss Parameters

Roof:	111 x 58	= ______	120
Wall:	112 x 81	= ______	121
Ground/exposed floor:	1 x 108	= ______	122
Windows:	0.9 x 115 x 109	= ______	123
Roof lights:	0.9 x 116 x 109	= ______	124
Doors:	117 x 110	= ______	125
Other:	118 x U-value	= ______	126
Ventilation heat loss:[2]	27 x 0.33 x 10	= ______	127
Heat Loss Coefficient:	120 + 121 + … + 126 + 127	= ______	128
Heat Loss Parameter:	128 / 9	= ______	129

Water-heating Energy Requirements

If hot water energy requirement is to be determined on the basis of floor area, go to steps 134 to 135. If energy requirement is to be based on predicted consumption, use steps 130 to 133.

Predicted hot water consumption:		= ______	130

Refer to table O for predicted consumption values

Temperature difference between supply and heated temperature:		= ______	131

Note: standard values for water at 55 °C heated temperature would be 36 °C for header tank within heated space and 49 °C for header tank outside heated space.

Energy requirement ($GJ.a^{-1}$):[3]	$(130 \times 14 \times 131 \times 4{,}186 \times 365.25) / 10^9$	= ______	132
Distribution losses:[4]	132 x 0.177	= ______	133

If instantaneous water heating at point of use, 133 = 0

Or:

Hot water energy requirement based on floor area:		= ______	134

Refer to table O1.

Distribution losses based on floor area:		= ______	135

Refer to table O1. If instantaneous water heating at point of use, 135 = 0

Hot water energy requirement:	132 or 134	= ______	136

---

[2] The heat loss from the ventilation of the dwelling is calculated by multiplying the volume of the dwelling by the effective air change rate, to determine how much warm air is being removed from the dwelling to be replaced by cooler fresh air. This is multiplied by the specific heat capacity of air, hence the constant 0.33 $kW.m^{-3}.K^{-1}$.

[3] 4,186 $J.kg^{-1}.K^{-1}$ is the specific heat capacity of water. 365.25 converts the consumption into an annual value, accounting for leap years.

[4] In the SAP assessment, the distribution losses, where applicable, are 17.7 percent of the hot water energy requirement, hence the constant.

Distribution losses: 133 or 135 = ______ 137

Note: *Refer to table O1. If instantaneous water heating at point of use, 136 and 137 = 0*
For community heating use table a, whether or not hot water tank present

Hot water storage volume (litres): = ______ 138

Note: *Capacity of hot water tank, or:* 50 x 14
If no hot water is stored, 138 = 0
If heated by community heating and no tank, 138 = 110

Hot water storage loss factor (table E) = ______ 139

Note: *If community heating and no tank, 139 = 0.0079*

Energy lost from hot water storage: 138 x 139 = ______ 140

Primary circuit losses (table F) = ______ 141

Output from water heater: 136 + 137 + 140 + 141 = ______ 142

Efficiency of water heater (table G1 or dG2, adjusted): = ______ 143

Energy required for water heating: (142 x 100) / 143 = ______ 144

Heat gains from water heating: (0.25 x 136) + (0.8 x (137 + 140 + 141)) = ______ 145

Internal Gains

If gains from lights, appliances, cooking and metabolic are to be determined on the basis of floor area, go to step 151.

Metabolic gains (W):[5] (115 x 14 x 90 x 52) / 8,760 = ______ 146

Mean wattage of light bulbs (W): = ______ 147

13.5 W represents compact fluorescent bulbs, 80 W represents tungsten bulbs.

Lighting gains (W):[6] (147 x 14 x 6 x 365.25) / 8,760 = ______ 148

Appliance gains (W):[7] (0.9 x total consumption x 1000) / 8,760 = ______ 149

Refer to table R to determine total consumption.

Cooking gains (W):[8] (total consumption x 1000) / 8,760 = ______ 150

Refer to table R or T to determine total consumption.

Or:

Lights, appliances, cooking and metabolic gains based on floor area: = ______ 151

Refer to table H.

---

5 The metabolic gains per occupant are 115 W. The constant 90 is to account for the occupancy of the dwelling; this assumes that it is occupied for 90 hours in each week, 54 percent of the total: 6 hours per day for 6 days and 18 hours per day for 1 day. This value can be varied in respect of the anticipated occupancy period. The constant 8,760 is the number of hours in a year.

6 The constant 6 is used on the basis of an assumed that each bulb will be used on average for 6 hours each day. The calculation also assumes one bulb per inhabitant. The values can be adjusted if necessary.

7 It is assumed that 90 percent of the energy used by appliances is incidental gain in the dwelling. The constant 1,000 in this and the next step convert the consumption form $kWh.a^{-1}$ into $Wh.a^{-1}$, and the constant 8,760 converts the value into watts, to be compatible with the SAP assessment.

8 It is assumed that 100 percent of the energy used in cooking is incidental gain in the dwelling.

Gains from lights, appliances, cooking and metabolic:

	(146 + 148 + 149 + 150) or 151	= ______	152
Additional gains from table H, if heated other than by community heating system:		= ______	153
Water heating:[9]	31.71 x 145	= ______	154
Total internal gains:	152 + 153 + 154	= ______	155

Solar Gains

By glazing orientation

Note: For values of solar flux, refer to table H1.

North:	area x flux	= ______	156
North east:	area x flux	= ______	157
East:	area x flux	= ______	158
South east:	area x flux	= ______	159
South:	area x flux	= ______	160
South west:	area x flux	= ______	161
West:	area x flux	= ______	162
North west:	area x flux	= ______	163
Roof lights:	area x flux	= ______	164
	156 + 157 +... + 163 + 164	= ______	165
Solar access factor (table J1):		= ______	166

Note: *For new dwellings where over shading not known 166 = 1*

Solar gains:	165 x 166	= ______	167
Total gains:	155 + 167	= ______	168
Gains/loss ratio:	168 / 128	= ______	169
Utilisation factor (table K):		= ______	170
Useful gains:	168 x 170	= ______	171

Mean internal temperature

Mean internal temperature of living area (table L):		= ______	172
Temperature adjustment (table G5, where applicable)		= ______	173
Adjustment gains	((171 / 128) – 4.0) x 0.2 x *R*	= ______	174

Note: *R* is determined from responsiveness column of table G1 or G4

Adjusted living room temperature:	172 + 173 + 174	= ______	175
Temperature difference between zones (table M):		= ______	176
Living area fraction:	living room area / 9	= ______	177
Rest of house fraction:	1 – 177	= ______	178
Mean internal temperature:	175 – (176 x 178)	= ______	179

---

[9] The constant 31.71 is to convert the value from step 145, which is in $GJ.a^{-1}$ into watts to be compatible with the other values in the internal gains calculation. 1 $GJ.a^{-1}$ is the equivalent of 277.78 $kWh.a^{-1}$; dividing this by the number of hours in one year, 8760, and multiplying by 1000 gives the value in watts. Personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.

Degree Days

Temperature rise from gains:	171 / 128	= ______	180
Base temperature:	179 – 180	= ______	181
Degree days (from 181 and table N):		= ______	182

Water Consumption

Predicted total consumption:	use ($l.p^{-1}.d^{-1}$)	= ______	183
Note: *Refer to table O for usage*			
Predicted dwelling consumption:	183 x 14	= ______	184
Rainwater storage capacity of dwelling:		= ______	185
Storage ratio:	185 / (56 x 184)	= ______	186
If 186 < 1, enter 186 into 187; if 186 ≥ 1, enter 1 into 187:		= ______	187
Potential rainwater available:	(1.8 x area of collection x rainfall) / 1095	= ______	188
Note: *Refer to table P for rainfall values*			
Rainwater available, accounting for storage:	187 x 188	= ______	189
Balance of available rainwater to consumption:	184 – 189	= ______	190
Potable consumption:	190 / 14	= ______	191
Note: If 191 < 6.5, enter 6.5 into 191			
Rainwater consumption:	183 – 191	= ______	192

Energy Consumption ($kWh.a^{-1}$)

- Space Heating

Useful energy requirement:[10]	0.0240 x 182 x 128	= ______	193

Note: *For community space and water heating systems, use steps 199 to 204.*

Conventional heating systems:

Fraction of heat from secondary system (table Q):		= ______	194
Efficiency of primary heating system:		= ______	195
Note: *(Table G1 or G2, adjusted if applicable by value shown in efficiency adjustment column of table G3, and by the efficiency adjustment column of G6)*			
Efficiency of secondary heating system (table G1):		= ______	196
Space heating – primary:	((1 – 194) x 193 x 100) / 195	= ______	197
Space heating – secondary:	(194 x 193 x 100) / 196	= ______	198

[10] In the SAP worksheet the constant 0.000 08604 is used as a conversion factor to convert the outcome of this product into $GJ.a^{-1}$, derived from the number of hours in a year divided by 10^9; personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000. Because the tool is in units of $kWh.a^{-1}$, 0.000 08604 is multiplied by 277.78 to convert from $GJ.a^{-1}$ to $kWh.a^{-1}$, to derive the constant 0.0240.

For community space heating:

Overall system efficiency: = ______ 199

Note: 100 percent, adjusted where appropriate by efficiency column, table G5.

Fraction of heat from CHP unit: = ______ 200

Note: From system design specification or operational records.

Fraction of heat from boilers:	1 – 200	= ______	201
Distribution loss factor, refer to table O2:		= ______	202
Space heating from CHP:	(193 x 200 x 100) / (199 x 202)	= ______	203
Space heating from boilers:	(193 x 201 x 100) / (199 x 202)	= ______	204
Primary Space Heating:	197 or (203 + 204)	= ______	205
Secondary Space Heating:	198	= ______	206

- Water Heating

Energy consumption for water heating:[11]	144 x 277.78	= ______	207

- Pumps and Fans

Electricity for pumps and fans:

130.6 kWh for each central heating pump		= ______	208
44.4 kWh for each boiler with fan assisted flue		= ______	209
For warm-air heating system fans	0.56 x 10	= ______	210
For full mechanical ventilation	1.11 x 10	= ______	211

Note: For community heating, 208 to 211 = 0, unless 211 applies.

Total for pumps and fans:	208 + 209 + 210 + 211	= ______	212

- Lights and Appliances

For consumption based on floor area, go to step 217.

Lights

Mean wattage of light bulbs	147	= ______	213
Energy consumption (kWh.a^{-1}):[12]	(213 x 14 x 6 x 365.25) / 1000	= ______	214

Appliances

Consumption based on specific appliance specification, value from table R: = ______ 215

Or:

Consumption based on floor area: value from table S: = ______ 216

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[11] The constant 277.78 is used to convert from GJ.a^{-1} to kWh.a^{-1}.

[12] The constant 6 is used on the basis of an assumed that each bulb will be used on average for 6 hours each day. The calculation also assumes one bulb per inhabitant. The values can be adjusted if necessary.

Total consumption: Lights and Appliances:	(214 + 215) or 216	= ______	217
- Cooking			
Total consumption for cooking (kWh.a^{-1}):		= ______	218
For values of cooking consumption, refer to table R or T:			
Energy Consumption: Inhabitation:	(205 + 206 + 207 + 212 + 217 + 218) / 9	= ______	219
Energy Generation		**(kWh.a^{-1})**	
Annual energy generation from photovoltaic panels:			
Solar energy available:			
Either based on daily sunlight:	kWpeak per day x 365.25	= ______	220
Or based on annual availability:		= ______	220
Refer to table U for annual values by location.			
Efficiency of panel: 0.19 or,	percentage efficient / 100	= ______	221
Generation capacity per m^2:	220 x 221, or 0.19 kW.m^{-2}	= ______	222
Area of photovoltaic array:		= ______	223
Generation per annum:	222 x 223	= ______	224
Annual energy generation from solar water panels:			
Area of panel:		= ______	225
Energy available:[13]	1.3 x 225	= ______	226
Load ratio:	136 / 226	= ______	227
Solar input per annum:[14]	((226 x 227) / (1 + 227)) x 277.78	= ______	228
Annual energy generation from wind turbines:			
Average monthly wind speed:	From meteorological data	= ______	229
Generator hub height:	From manufacturer's data	= ______	230
Roughness length: (0.4 m for urban areas)		= ______	231
Wing speed at generator height:	ln (230 / 231) / ln (10 / 231)	= ______	232
	229 x 232	= ______	233
Annual energy yield:	From 233 and manufacturer's data	= ______	234
Annual energy generation from wind sources:	234 x number of generators	= ______	235
Annual energy generation from other sources:		= ______	236

[13] The constant of 1.3 is the typical solar radiation level in the United Kingdom taking into account the typical efficiency of solar water panels, derived from measured analysis; personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.

[14] The constant 277.78 is used to convert from GJ.a^{-1} to kWh.a^{-1}.

Total generation by dwelling:	224 + 228 + 235 + 236	= ______	237
Energy Generation: Inhabitation:	237 / 9	= ______	238

CO_2 Emissions

Refer to table V for CO_2 emission factors for different fuel types.

- For conventional and community heating without CHP

Primary space heating:	205 x emission factor	= ______	239
If heated by community boilers:	(204 / 0.75) x emission factor		
Secondary space heating:	206 x emission factor	= ______	240
If heated by community boilers, enter 0.			
From water heating:	207 x emission factor	= ______	241
If heated by community boilers:	((207 x 202) / 0.75) x emission factor		

- For community heating with CHP

Electrical efficiency of CHP unit, 0.25 or:		= ______	242
Note: From system design specification or operational records.			
Heat efficiency of CHP unit, 0.50 or:		= ______	243
Note: From system design specification or operational records.			
CO_2 emission factor for CHP fuel ($kgCO_2.kWh^{-1}$):		= ______	244
CO_2 emission factor for electricity ($kgCO_2.kWh^{-1}$):		= ______	245
CO_2 emitted by CHP per kWh of generated electricity:			
	244 / 242	= ______	246
Heat to power ratio, kWh heat / kWh electricity:			
	243 / 242	= ______	247
CO_2 emission factor for heat:	(246 – 245) / 247	= ______	248
Note: If negative, enter 0.			
Water heated by CHP:	(207 x 200 x 202) x 248	= ______	249
Water heated by boilers:	((207 x 201 x 202) / 0.75) x emission factor	= ______	250
Space heated by immersion heater:	207 x emission factor	= ______	251
Space heating – CHP:	203 x 248	= ______	252
Space heating – Boilers:	(204 / 0.75) x emission factor	= ______	253

- Gross CO_2 Emission

Primary space heating:	239 or (251 + 252 + 253)	= ______	254
Secondary space heating:	240	= ______	255

Water heating:	241 or (249 + 250)	= ______	256
Pumps and fans:	212 x emission factor	= ______	257
Lights and appliances:	217 x emission factor	= ______	258
Cooking:	218 x emission factor	= ______	259
From other fuel consumption:	total annual consumption x emission factor	= ______	260
From potable water consumption:	191 x 14 x 0.33	= ______	261
Gross CO_2 Emission:	(254 + 255 +… + 260 + 261) / 9	= ______	262

- Net CO_2 Emission

Assimilation from green space:	area of green space x 0.660	= ______	263
Reduction from energy generation:	(224 + 235 + 236) x equivalent emission factor	= ______	264
	228 x equivalent emission factor	= ______	265
Net CO_2 emission:	262 – ((263 + 264 + 265) / 9)	= ______	266

Pollutant Emissions during Inhabitation

Note: A breakdown of emission factors is given in table W. These can be used to determine the emission level of a specific pollutant.

- For conventional and community heating without CHP

Primary space heating:	(205 / (219 x 9)) x emission factor	= ______	267
If heated by community boilers:	((204 / 0.75) / (219 x 9)) x emission factor		
Secondary space heating:	(206 / (219 x 9)) x emission factor	= ______	268
If heated by community boilers, enter 0.			
From water heating:	(207 / (219 x 9)) x emission factor	= ______	269
If heated by community boilers:	(((207 x 202) / 0.75) / (219 x 9)) x emission factor		

- For community heating with CHP

Emission factor for CHP fuel:		= ______	270
Emission factor for electricity:		= ______	271
Pollution emitted by CHP per kWh of generated electricity:	270 / 242	= ______	272
Heat to power ratio, kWh heat / kWh electricity:	243 / 242	= ______	273
Pollutant emission factor for heat:	(272 – 271) / 273	= ______	274
Note: If negative, enter 0.			
Water heated by CHP:	((207 x 200 x 202) / (219 x 9)) x 274	= ______	275

Water heated by boilers: (((207 x 201 x 202) / 0.75) / (219 x 9)) x emission factor = ______ 276

Space heated by immersion heater: (207 / (219 x 9)) x emission factor = ______ 277

Space heating – CHP: (203 / (219 x 9)) x 274 = ______ 278

Space heating – Boilers: ((204 / 0.75) / (219 x 9)) x emission factor = ______ 279

Total Pollutant Emissions during Inhabitation:

From primary space heating: 267 or (277 + 278 + 279) = ______ 280

From secondary space heating: 268 = ______ 281

From water heating: 269 or (275 + 276) = ______ 282

From pumps and fans: (212 / (219 x 9)) x emission factor = ______ 283

From lights and appliances: (217 / (219 x 9)) x emission factor = ______ 284

From cooking: (218 / (219 x 9)) x emission factor = ______ 285

From other fuel consumption: (total annual consumption / (219 x 9)) x emission factor = ______ 286

Gross Pollution: Energy Consumption during Inhabitation:

280 + 281 + … + 285 + 286 = ______ 287

Net Pollution: Energy Consumption during Inhabitation:

Reduction from energy generation: ((224 + 235 + 236) / (219 x 9)) x equivalent emission factor = ______ 288

(228 / (219 x 9)) x equivalent emission factor = ______ 289

Net Pollution: Energy Consumption during Inhabitation:

287 – (288 + 289) = ______ 290

Pollution: Energy Consumption during Inhabitation:

290 = ______ 291

Definition of Life span

Life span benchmark: = ______ 292

Replacement ratio: dwelling life / component life

Note: Only use replacement ratio if > 1; for component life spans, refer to table X.

Roof, external finish - replacement ratio: 292 / life span = ______ 293

Roof, structure - replacement ratio: 292 / life span = ______ 294

Roof, insulation - replacement ratio: 292 / life span = ______ 295

Roof, internal finish - replacement ratio: 292 / life span = ______ 296

Wall, external finish - replacement ratio: 292 / life span = ______ 297

Wall, structure - replacement ratio: 292 / life span = ______ 298

Wall, insulation - replacement ratio: 292 / life span = ______ 299

Wall, internal finish - replacement ratio: 292 / life span = ______ 300

Windows and roof lights - replacement ratio 292 / life span = ______ 301
Floor, internal finish - replacement ratio: 292 / life span = ______ 302
Floor, structure - replacement ratio: 292 / life span = ______ 303
Floor, insulation - replacement ratio: 292 / life span = ______ 304
Internal staircase: 292 / life span = ______ 305
Photovoltaic panels - replacement ratio: 292 / life span = ______ 306
Solar water panels - replacement ratio: 292 / life span = ______ 307

Note: This calculation can be taken as far as desired, but should at least be completed for the above materials.

Embodied Energy

Note: Refer to table C for density and embodied energy values.

If dwelling is one flat or apartment within a block, enter number of dwellings within block: = ______ 308

- Foundations

If strip/trench footing:

Volume of strip or trench: actual, or strip depth x width x (12 + length of internal foundations) = ______ 309

Mass = 309 x density (kg.m^{-3}) = ______ 310

Embodied energy = 310 x embodied energy (kWh.kg^{-1}) = ______ 311

Volume of wall below ground level: actual, or (59 + 67) x (12 + length of internal foundations) x depth = ______ 312

Mass = 312 x density (kg.m^{-3}) = ______ 313

Embodied energy = 313 x embodied energy (kWh.kg^{-1}) = ______ 314

Volume of cavity fill, where applicable: actual, or cavity width x (12 + length of internal foundations) x depth = ______ 315

Mass = 315 x density (kg.m^{-3}) = ______ 316

Embodied energy = 316 x embodied energy (kWh.kg^{-1}) = ______ 317

Embodied energy: 311 + 314 + 317 = ______ 318

If pile foundation:

Volume of piles: actual, or cross sectional area x depth x number of piles = ______ 319

Volume of pile caps: actual, or cross sectional area x depth x number of pile caps = ______ 320

Mass = (319 + 320) x density (kg.m^{-3}) = ______ 321

Embodied energy = 321 x embodied energy (kWh.kg^{-1}) = ______ 322

Volume of ground beams: actual, or depth x width x ((perimeter + length of internal foundations) – pile cap width) = ______ 323

Mass =	323 x density (kg.m^{-3})	= ______	324
Embodied energy =	324 x embodied energy (kWh.kg^{-1})	= ______	325
Embodied energy:	322 + 325	= ______	326

If pad foundation:

Volume of pads: actual, or	width x length x depth x number of pads	= ______	327
Mass =	327 x density (kg.m^{-3})	= ______	328
Embodied energy =	328 x embodied energy (kWh.kg^{-1})	= ______	329

Volume of ground beams: actual, or

depth x width x ((perimeter + length of internal foundations) – pile cap width)

		= ______	330
Mass =	330 x density (kg.m^{-3})	= ______	331
Embodied energy =	331 x embodied energy (kWh.kg^{-1})	= ______	332
Embodied energy:	329 + 332	= ______	333

Note: For pile and pad foundations, if wall is carried on separate strip foundation, use steps 309 to 318 to account for this.

If raft:

For solid slab raft, use concrete ground floor calculation (steps 382 to 394) to determine embodied energy of slab. If beam and slab raft, use concrete ground floor and ground beam foundations (steps 323 to 326) to determine embodied energy of slab and ground beams (NB: add to perimeter value the length of internal ground beams).

If continuous column:

Use strip foundation (steps 309 to 318) to account for the strip footing.

Embodied energy – foundations:	318, 326, or 333	= ______	334

- Basement, if appropriate

Perimeter of basement:	12, or other	= ______	335
Depth of basement:		= ______	336
Volume of walls: actual, or	width x 335 x 336	= ______	337
Mass =	337 x density (kg.m^{-3})	= ______	338
Embodied energy =	338 x embodied energy (kWh.kg^{-1})	= ______	339

Note: *Do not count walls, if accounted for by depth of wall in strip foundations, steps 312 to 314.*

Volume of tanking: actual, or	thickness x 335 x 336	= ______	340
Mass =	340 x density (kg.m^{-3})	= ______	341
Embodied energy =	341 x embodied energy (kWh.kg^{-1})	= ______	342

Volume of floor: actual, or	area (1 or other) x mean depth (m)	= ______	343
Mass =	343 x density (kg.m^{-3})	= ______	344
Embodied energy =	344 x embodied energy (kWh.kg^{-1})	= ______	345
Volume of wall insulation: actual, or	thickness x 335 x height	= ______	346
Mass =	346 x density (kg.m^{-3})	= ______	347
Embodied energy =	347 x embodied energy (kWh.kg^{-1})	= ______	348
Volume of floor insulation: actual, or	area (1 or other) x thickness (m)	= ______	349
Mass =	349 x density (kg.m^{-3})	= ______	350
Embodied energy =	350 x embodied energy (kWh.kg^{-1})	= ______	351
Volume of hardcore: actual, or	area (1 or other) x depth	= ______	352
Mass =	352 x density (kg.m^{-3})	= ______	353
Embodied energy =	353 x embodied energy (kWh.kg^{-1})	= ______	354
Embodied energy - basement:	339 + 342 + 345 + 348 + 351 + 354	= ______	355

- Frame, if appropriate

Repeat steps 359 to 361 if frame is constructed from more than one material.

Columns:	cross sectional area x height x number of columns	= ______	356
Beams:	cross sectional area x length x number per floor	= ______	357
	357 x (11 - 1)	= ______	358

Note: Do not double count beams used in floor construction (e.g. in beam and block flooring), which are accounted for elsewhere.

Total volume of frame: actual, or	356 + 358	= ______	359
Mass =	359 x density (kg.m^{-3})	= ______	360
Embodied energy - frame:	360 x embodied energy (kWh.kg^{-1})	= ______	361

- Ground Floor

If timber:

Number of joists: actual number, or	(length of floor / joist spacing) + 1	= ______	362
Volume per joist:	joist length x depth x width	= ______	363
Volume of joists:	362 x 363 x 303	= ______	364
Volume of boarding:	1 x 84 x 302	= ______	365
Volume of timber:	364 + 365	= ______	366
Mass =	366 x density (kg.m^{-3})	= ______	367
Embodied energy =	367 x embodied energy (kWh.kg^{-1})	= ______	368

Sleeper walls, if applicable:

Volume of brick: actual, or	0.75 x no of sleeper walls x length x height x 112.5	= ______	369
Mass =	369 x density (kg.m^{-3})	= ______	370

Embodied energy =	370 x embodied energy ($kWh.kg^{-1}$)	=	371
Volume of insulation: actual, or	1 x 86	=	372
Mass =	372 x density ($kg.m^{-3}$)	=	373
Embodied energy =	373 x embodied energy ($kWh.kg^{-1}$) x 304	=	374
Volume of concrete (if applicable): actual, or	1 x depth	=	375
Mass =	375 x density ($kg.m^{-3}$)	=	376
Embodied energy =	376 x embodied energy ($kWh.kg^{-1}$)	=	377
Volume of hardcore: actual, or	1 x depth	=	378
Mass =	378 x density ($kg.m^{-3}$)	=	379
Embodied energy =	379 x embodied energy ($kWh.kg^{-1}$)	=	380
Embodied energy:	368 + 371 + 374 + 377 + 380	=	381

If concrete slab:

Volume of screed: actual, or	1 x depth	=	382
Mass =	382 x density ($kg.m^{-3}$)	=	383
Embodied energy =	383 x embodied energy ($kWh.kg^{-1}$) x 302	=	384
Volume of concrete: actual, or	1 x depth	=	385
Mass =	385 x density ($kg.m^{-3}$)	=	386
Embodied energy =	386 x embodied energy ($kWh.kg^{-1}$) x 303	=	387
Volume of insulation: actual, or	1 x 86	=	388
Mass =	388 x density ($kg.m^{-3}$)	=	389
Embodied energy =	389 x embodied energy ($kWh.kg^{-1}$) x 304	=	390
Volume of hardcore: actual, or	1 x depth	=	391
Mass =	391 x density ($kg.m^{-3}$)	=	392
Embodied energy =	392 x embodied energy ($kWh.kg^{-1}$)	=	393
Embodied energy:	384 + 387 + 390 + 393	=	394

If concrete beam and block:

Number of beams: actual number, or	(length of floor / beam spacing) + 1	=	395
Volume per beam: actual, or	area of beam section x beam length	=	396
Volume of beams: actual, or	395 x 396	=	397
Number of blocks: actual, or	width of floor / width of block	=	398
	398 x (395 - 1)	=	399
Volume per block: actual, or	area of block section x block length	=	400
Volume of blocks: actual, or	399 x 400	=	401
Volume of concrete: actual, or			
For beams: Mass =	397 x density ($kg.m^{-3}$)	=	402
Embodied energy =	402 x embodied energy ($kWh.kg^{-1}$)	=	403
For blocks: Mass =	401 x density ($kg.m^{-3}$)	=	404

Embodied energy =	404 x embodied energy ($kWh.kg^{-1}$)	= ______	405
Volume of screed, if applicable: actual, or	1 x screed depth	= ______	406
Mass =	406 x density ($kg.m^{-3}$)	= ______	407
Embodied energy =	407 x embodied energy ($kWh.kg^{-1}$) x 302	= ______	408
Volume of insulation: actual, or	1 x 86	= ______	409
Mass =	409 x density ($kg.m^{-3}$)	= ______	410
Embodied energy =	410 x embodied energy ($kWh.kg^{-1}$) x 304	= ______	411
Volume of hardcore: actual, or	1 x depth	= ______	412
Mass =	412 x density ($kg.m^{-3}$)	= ______	413
Embodied energy =	413 x embodied energy ($kWh.kg^{-1}$)	= ______	414
Embodied energy:	403 + 405 + 408 + 411 + 414	= ______	415
Embodied energy – ground floor:	381, 394 or 415	= ______	416

- External Walls

External wall length (m):		= ______	417

Solid and masonry walls:

External finish:			
Volume of material: actual, or	59 x 112	= ______	418
Mass =	418 x density ($kg.m^{-3}$)	= ______	419
Embodied energy =	419 x embodied energy ($kWh.kg^{-1}$) x 297	= ______	420
Outer leaf,			
Volume of material: actual, or	61 x 112	= ______	421
Mass =	421 x density ($kg.m^{-3}$)	= ______	422
Embodied energy =	422 x embodied energy ($kWh.kg^{-1}$) x 298	= ______	423
Insulation,			
Volume of material: actual, or	65 x 112	= ______	424
Mass =	424 x density ($kg.m^{-3}$)	= ______	425
Embodied energy =	425 x embodied energy ($kWh.kg^{-1}$) x 299	= ______	426
Inner leaf,			
Volume of material: actual, or	67 x 112	= ______	427
Mass =	427 x density ($kg.m^{-3}$)	= ______	428
Embodied energy =	428 x embodied energy ($kWh.kg^{-1}$) x 298	= ______	429
Internal finish,			
Volume of material: actual, or	69 x 112	= ______	430
Mass =	430 x density ($kg.m^{-3}$)	= ______	431
Embodied energy =	431 x embodied energy ($kWh.kg^{-1}$) x 300	= ______	432

Embodied energy:	420 + 423 + 426 + 429 + 432	= ______ 433
Timber frame walls:		
External finish,		
Volume of material: actual, or	59 x 112	= ______ 434
Mass =	434 x density (kg.m^{-3})	= ______ 435
Embodied energy =	435 x embodied energy (kWh.kg^{-1}) x 297	= ______ 436
Outer leaf,		
Volume of material: actual, or	61 x 112	= ______ 437
Mass =	437 x density (kg.m^{-3})	= ______ 438
Embodied energy =	438 x embodied energy (kWh.kg^{-1})	= ______ 439
Sheathing ply,		
Volume of material: actual, or	63 x 112	= ______ 440
Mass =	440 x density (kg.m^{-3})	= ______ 441
Embodied energy =	441 x embodied energy (kWh.kg^{-1}) x 298	= ______ 442
Insulation,		
Volume of material: actual, or	74 x 65 x 112	= ______ 443
Mass =	443 x density (kg.m^{-3})	= ______ 444
Embodied energy =	444 x embodied energy (kWh.kg^{-1}) x 299	= ______ 445
Inner leaf,		
Volume of material: actual, or	(417 / stud spacing) +1	= ______ 446
	446 x stud width x stud depth x height (13)	= ______ 447
	sole plate width x sole plate depth x 417	= ______ 448
	head plate width x head plate depth x 417	= ______ 449
	header joist width x depth x 417 x 2	= ______ 450
	11 x (448 + 449 + 450)	= ______ 451
	447 + 451	= ______ 452
Mass =	452 x density (kg.m^{-3})	= ______ 453
Embodied energy =	453 x embodied energy (kWh.kg^{-1}) x 298	= ______ 454
Internal finish, volume of material:	69 x 112	= ______ 455
Mass =	455 x density (kg.m^{-3})	= ______ 456
Embodied energy =	456 x embodied energy (kWh.kg^{-1}) x 300	= ______ 457
Embodied energy:	436 + 439 + 442 + 445 + 454 + 457	= ______ 458

- Party walls:

Solid and masonry walls:

Party wall length (m):	12 - 417	= ______ 459

Insulation,			
Volume of material: actual, or	thickness x 459 x 13	= ______	460
Mass =	460 x density (kg.m^{-3})	= ______	461
Embodied energy =	461 x embodied energy (kWh.kg^{-1}) x 299	= ______	462
Note: *If applicable*			
Inner leaf			
Volume of material: actual, or	thickness (67) x 459 x 13	= ______	463
Mass =	463 x density (kg.m^{-3})	= ______	464
Embodied energy =	464 x embodied energy (kWh.kg^{-1}) x 298	= ______	465
Internal finish,			
Volume of material: actual, or	thickness (69) x 459 x 13	= ______	466
Mass =	466 x density (kg.m^{-3})	= ______	467
Embodied energy =	467 x embodied energy (kWh.kg^{-1}) x 300	= ______	468
Embodied energy:	462 + 465 + 468	= ______	469
Timber frame walls:			
Sheathing ply,			
Volume of material: actual, or	63 x 459 x 13	= ______	470
Mass =	470 x density (kg.m^{-3})	= ______	471
Embodied energy =	471 x embodied energy (kWh.kg^{-1}) x 298	= ______	472
Insulation,			
Volume of material: actual, or	74 x 65 x 459 x 13	= ______	473
Mass =	473 x density (kg.m^{-3})	= ______	474
Embodied energy =	474 x embodied energy (kWh.kg^{-1}) x 299	= ______	475
Note: *If applicable*			
Inner leaf,			
Volume of material: actual, or	459 / stud spacing	= ______	476
	476 x stud width x stud depth x height (13)	= ______	477
	sole plate width x depth x 459	= ______	478
	head plate width x depth x 459	= ______	479
	header joist width x depth x 459 x 2	= ______	480
	11 x (478 + 479 + 480)	= ______	481
	477 + 481	= ______	482
Mass =	482 x density (kg.m^{-3})	= ______	483
Embodied energy =	483 x embodied energy (kWh.kg^{-1}) x 298	= ______	484
Internal finish,			
Volume of material: actual, or	69 x 459 x 13	= ______	485
Mass =	485 x density (kg.m^{-3})	= ______	486

Embodied energy =	486 x embodied energy (kWh.kg^{-1}) x 300	= ______	487
Embodied energy:	472 + 475 + 484 + 487	= ______	488

- Internal Load-bearing walls (if applicable)

Length of internal load-bearing walls (m):		= ______	489

Solid and masonry walls:

Wall,			
Volume of material: actual, or	thickness x 489 x height	= ______	490
Mass =	490 x density (kg.m^{-3})	= ______	491
Embodied energy =	491 x embodied energy (kWh.kg^{-1})	= ______	492
Finish,			
Volume of material: actual, or	69 x 489 x height x 2	= ______	493
Mass =	493 x density (kg.m^{-3})	= ______	494
Embodied energy =	494 x embodied energy (kWh.kg^{-1}) x 300	= ______	495
Embodied energy:	492 + 495	= ______	496

Timber frame walls:

Sheathing ply,			
Volume of material: actual, or	63 x 489 x height	= ______	497
Mass =	497 x density (kg.m^{-3})	= ______	498
Embodied energy =	498 x embodied energy (kWh.kg^{-1}) x 298	= ______	499
Inner leaf,			
Volume of material: actual, or	489 / stud spacing	= ______	500
	500 x stud width x stud depth x height	= ______	501
	sole plate width x sole plate depth x 489	= ______	502
	head plate width x head plate depth x 489	= ______	503
	header joist width x depth x 489 x 2	= ______	504
	501+ (11 x (502 + 503 + 504))	= ______	505
Mass =	505 x density (kg.m^{-3})	= ______	506
Embodied energy =	506 x embodied energy (kWh.kg^{-1}) x 298	= ______	507
Internal finish,			
Volume of material: actual, or	69 x 489 x height x 2	= ______	508
Mass =	508 x density (kg.m^{-3})	= ______	509
Embodied energy =	509 x embodied energy (kWh.kg^{-1}) x 300	= ______	510
Embodied energy:	499 + 507 + 510	= ______	511
Embodied energy – walls:	either (433 + 469 + 496) or (458 + 488 + 511)	= ______	512

- Windows and Roof lights

Volume of glass: actual, or	(115 + 116) x pane thickness x level of glazing	= ______	513
Mass =	514 x density ($kg.m^{-3}$)	= ______	514
Embodied energy:	515 x embodied energy ($kWh.kg^{-1}$) x 301	= ______	515
Perimeter windows and roof lights:		= ______	516
Section of frame:		= ______	517
Volume of window and roof light frames:	516 x 517	= ______	518
Mass =	518 x density ($kg.m^{-3}$)	= ______	519
Embodied energy:	519 x embodied energy ($kWh.kg^{-1}$) x 301	= ______	520
Embodied energy – windows and roof lights:	515 + 520	= ______	521

- Internal Floors

If timber:

For first floor:

Number of joists: actual number, or	(length of first floor / joist spacing) + 1	= ______	522
Volume per joist: actual, or	joist length x depth x width	= ______	523
Volume of joists: actual, or	522 x 523	= ______	524
Volume of boarding: actual, or	3 x floorboard depth	= ______	525
Volume of timber: actual, or	524 + 525	= ______	526
Mass =	526 x density ($kg.m^{-3}$)	= ______	527
Embodied energy =	527 x embodied energy ($kWh.kg^{-1}$) x 303	= ______	528

Soffit:

Volume of material: actual, or	3 x thickness	= ______	529
Mass =	529 x density ($kg.m^{-3}$)	= ______	530
Embodied energy =	530 x embodied energy ($kWh.kg^{-1}$) x 296	= ______	531
Embodied energy:	((528 + 531) / 3) x (3 + 5 + 7)	= ______	532

If concrete beam and block:

For first floor:

Number of beams: actual number, or	(length of floor / beam spacing) + 1	= ______	533
Volume per beam: actual, or	area of beam section x beam length	= ______	534
Volume of beams: actual, or	533 x 534	= ______	535
Number of blocks:	width of floor / width of block	= ______	536
	536 x (533 - 1)	= ______	537
Volume per block: actual, or	area of block section x block length	= ______	538
Volume of blocks: actual, or	537 x 538	= ______	539
Volume of concrete: actual, or			
For beams: Mass =	535 x density ($kg.m^{-3}$)	= ______	540

	Embodied energy =	540 x embodied energy ($kWh.kg^{-1}$) x 303	= ______	541
For blocks:	Mass =	539 x density ($kg.m^{-3}$)	= ______	542
	Embodied energy =	542 x embodied energy ($kWh.kg^{-1}$) x 303	= ______	543
Volume of screed, if applicable:		3 x screed depth	= ______	544
	Mass =	544 x density ($kg.m^{-3}$)	= ______	545
	Embodied energy =	545 x embodied energy ($kWh.kg^{-1}$) x 302	= ______	546
Soffit:				
Volume of material: actual, or		3 x thickness	= ______	547
	Mass =	547 x density ($kg.m^{-3}$)	= ______	548
	Embodied energy =	548 x embodied energy ($kWh.kg^{-1}$) x 296	= ______	549
Embodied energy:		((541 + 543 + 546 + 549) / 3) x (3 + 5 + 7)	= ______	550
Embodied energy – internal floors:		532 or 550	= ______	551

- Internal Staircases

Number of flights:		11 – 1	= ______	552

Stairs other than pre cast concrete:

Note: for pre cast concrete go on to steps 574 to 580.

Number of treads:			= ______	553
Tread length (m):			= ______	554
Tread width (m):			= ______	555
Tread thickness (m):			= ______	556
Volume of treads: actual, or		553 x 554 x 555 x 556	= ______	557
	Mass =	557 x density ($kg.m^{-3}$)	= ______	558
	Embodied energy =	558 x embodied energy ($kWh.kg^{-1}$)	= ______	559
Number of risers:		553 + 1	= ______	560
Riser height (m):			= ______	561
Riser width (m):			= ______	562
Riser thickness (m):			= ______	563
Volume of treads: actual, or		560 x 561 x 562 x 563	= ______	564
	Mass =	564 x density ($kg.m^{-3}$)	= ______	565
	Embodied energy =	565 x embodied energy ($kWh.kg^{-1}$)	= ______	566
Staircase length (m):			= ______	567
String depth (m):			= ______	568
String thickness (m):			= ______	569
Volume of strings: actual, or		2 x 567 x 568 x 569	= ______	570
	Mass =	570 x density ($kg.m^{-3}$)	= ______	571
	Embodied energy =	571 x embodied energy ($kWh.kg^{-1}$)	= ______	572
Embodied energy:		(559 + 566 + 572) x 552 x 305	= ______	573

If pre cast concrete:			
Staircase length (m):		= ______	574
Staircase width (m):		= ______	575
Mean staircase slab thickness (m):		= ______	576
Volume of staircase: actual, or	574 x 575 x 576	= ______	577
Mass =	577 x density (kg.m^{-3})	= ______	578
Embodied energy =	578 x embodied energy (kWh.kg^{-1})	= ______	579
Embodied energy:	579 x 552 x 305	= ______	580
Embodied Energy – Internal Staircases:	573 or 580	= ______	581

- Roof

Outer finish:			
Percent overlap of finish material:	(area of overlap / area of tile or sheet) +1	= ______	582
Volume of material: actual, or	111 x thickness x 582	= ______	583
Mass =	583 x density (kg.m^{-3})	= ______	584
Embodied energy =	584 x embodied energy (kWh.kg^{-1}) x 293	= ______	585
Waterproof layer:			
Volume of material: actual, or	111 x thickness	= ______	586
Mass =	586 x density (kg.m^{-3})	= ______	587
Embodied energy =	587 x embodied energy (kWh.kg^{-1}) x 293	= ______	588

Structure, *if timber:*			
Primary:	volume per truss or joist and firring x number of trusses/joists	= ______	589
Secondary:	volume per batten x number of battens	= ______	590
Deck/sheathing:	area of roof x 32	= ______	591
Volume of timber: actual, or	589 + 590 + 591	= ______	592
Mass =	592 x density (kg.m^{-3})	= ______	593
Embodied energy =	593 x embodied energy (kWh.kg^{-1}) x 294	= ______	594

Structure, *if steel:*			
Primary: actual volume, or	cross sectional area of beam x length	= ______	595
	595 x number of beams	= ______	596
Note: actual number, or (length of roof / beam spacing) + 1			
Mass =	596 x density (kg.m^{-3})	= ______	597
Embodied energy =	597 x embodied energy (kWh.kg^{-1}) x 294	= ______	598
Volume of insulation: actual, or	44 or 51 x depth x area of roof	= ______	599
Note: Omit 44 and 51 (fractional area) if insulation is not laid between joists		= ______	600
Mass =	600 x density (kg.m^{-3})	= ______	601

Embodied energy =	601 x embodied energy ($kWh.kg^{-1}$) x 295	= ______	602
Volume of internal finish: actual, or	40 x area of roof	= ______	603
Mass =	603 x density ($kg.m^{-3}$)	= ______	604
Embodied energy =	604 x embodied energy ($kWh.kg^{-1}$) x 296	= ______	605
Embodied energy – roof:	585 + 588 + (594 or 598) + 602 + 605	= ______	606

For house:

Embodied energy of materials in dwelling: 334 + 355 + 361 + 416 + 512 + 521 + 551 + 581 + 606 = ______ 607

For flat:

Embodied energy of materials in dwelling:

((334 + 355 + 361 + 416 + 602) / 308) + 512 + 521 + 551 + 581 = ______ 608

Anticipated percentage of construction waste: = ______ 609

Note: Typical waste benchmark = 10%, target benchmark = 2.5%

Embodied energy in photovoltaic panels:	223 x embodied energy ($kWh.m^{-2}$) x 306	= ______	610
Embodied energy in solar water panels:	225 x embodied energy ($kWh.m^{-2}$) x 307	= ______	611
Ecological Weight: Embodied Energy:	((607 or 608 x (1 + (609 / 100))) + 610 + 611) / 9	= ______	612

Embodied CO_2

Embodied energy by fuel type:	612 / fuel type ratio	= ______	613
CO_2 emissions fuel-type one:	613 x emissions factor	= ______	614
CO_2 emissions fuel-type two:	613 x emissions factor	= ______	615
CO_2 emissions fuel-type three:	613 x emissions factor	= ______	616
Note: *Repeat for each fuel type.*			
Ecological Weight: Embodied CO_2:	(614 + 615 + 616)	= ______	617

HCFC Emissions

Volume of insulation: $Vi_{roof} + Vi_{walls} + Vi_{floor}$

From embodied energy calculations: (346 + 348) + (372, 388 or 409) + (424 or 443) + 599 = ______ 618

Emissions: 618 x emission factor = ______ 619

Note: *Refer to table Y for emission factors*

Other Greenhouse Gas Emissions: 619 = ______ 620

Scoring

Energy Consumption: Inhabitation:	(25 / 219) x 1.784	=	621
Energy Generation: Inhabitation:	(238 / 219) x 0.539	=	622
Ventilation:	(0.45 / 27) x 0.160	=	623
Air Tightness:	(0.17 / 21) x 0.159	=	624
Ecological Weight: Embodied Energy:	(250 / 612) x 0.306	=	625
CO_2 Emissions: Inhabitation:	(10.7 / 266) x 0.266	=	626
Design Life Span:	(288 / 120) x 0.126	=	627
Pollution: Energy Consumption Inhabitation:	(1.004 / 291) x 0.097	=	628
Thermal Performance – U_{roof}:	(0.08 / 58) x ((111 / (119 - 113)) x 0.054)	=	629
Thermal Performance – U_{wall}:	(0.12 / 81) x ((112 / 119 - 113)) x 0.054)	=	630
Thermal Performance – U_{floor}:	(0.13 / 108) x ((114 / (119 - 113)) x 0. 054)	=	631
Thermal Performance – U_{window}:	(0.8 / 109) x (((115 + 116) / (119 - 113)) x 0. 054)	=	632
Thermal Performance – U_{door}:	(0.6 / 110) x ((117 / (119 - 113)) x 0. 054)	=	633
Ecological Weight: Embodied CO_2:	(90 / 617) x 0.037	=	634
Other Green House Gas Emissions:	(1 / 620) x 0.034	=	635
Water Consumption: Total:	(41.8/ 183) x 0.016	=	636
Water Consumption: Potable/mains:	(6.5 / 191) x 0.017	=	637
Aggregate value:	621 + 622 + ... + 636 + 637	=	638
Score:	(638 / 3.595) x 100	=	639

Additional Statistical Data:

Relative Embodied and Inhabitation Energy Consumption

Ecological Weight: Embodied Energy, annual equivalent:

612 / 292 = 640

Ratio of Energy Consumption: Inhabitation to embodied energy:

219 / 640 = 641

Relative Embodied and Inhabitation CO_2 Emissions

Ecological Weight: Embodied CO_2, annual equivalent:

617 / 292 = 642

Ratio of CO_2 Emissions: Inhabitation to embodied CO_2:

266 / 642 = 643

Gross Lifetime Energy Consumption:	((219 x 292) + 612) x 9	=	644
Net Lifetime Energy Consumption:	(((219 – 238) x 292) + 612) x 9	=	645

Lifecycle Energy Costs:

Refer to Table Z for energy costs.

Primary space heating fuel cost (£.kWh^{-1}): = ______ 646

$\sum_{292-1}^{0} (646 \times 205) \times 1.02^{n}$ = ______ 647

Secondary space heating fuel cost (£.kWh^{-1}): = ______ 648

$\sum_{292-1}^{0} (648 \times 206) \times 1.02^{n}$ = ______ 649

Water heating fuel cost (£.kWh^{-1}): = ______ 650

$\sum_{292-1}^{0} (650 \times 207) \times 1.02^{n}$ = ______ 651

Pumps and fans fuel cost (£.kWh^{-1}): = ______ 652

$\sum_{292-1}^{0} (652 \times 212) \times 1.02^{n}$ = ______ 653

Lights and appliances fuel cost (£.kWh^{-1}): = ______ 654

$\sum_{292-1}^{0} (654 \times 217) \times 1.02^{n}$ = ______ 655

Cooking fuel cost (£.kWh^{-1}): = ______ 656

$\sum_{292-1}^{0} (656 \times 218) \times 1.02^{n}$ = ______ 657

Standing charges, if applicable (£.annum^{-1}): = ______ 658

$\sum_{292-1}^{0} 658 \times 1.02^{n}$ = ______ 659

Total lifecycle energy cost: 647 + 649 + 651 + 653 + 655 + 657 + 659 = ______ 660

Lifecycle energy cost per unit floor area: 660 / 9 = ______ 661

Annual lifecycle energy cost per unit floor area:

661 / 292 = ______ 662

Lifecycle Water Costs:

Refer to Table AA for water costs.

Potable water cost (£.litre^{-1}): = ______ 663

Dwelling annual cost: 191 x 14 x 365.25 x 663 = ______ 664

$\sum_{292-1}^{0} 664 \times 1.02^{n}$ = ______ 665

Sewerage water cost (£.litre^{-1}): = ______ 666

Dwelling annual cost: 191 x 14 x 365.25 x 666 = ______ 667

	$\sum_{292-1}^{0} 667 \times 1.02^{n}$	= ______	668
Standing charges, if applicable (£.annum^{-1}):		= ______	669
	$\sum_{292-1}^{0} 669 \times 1.02^{n}$	= ______	670
Total lifecycle water cost:	665 + 668 + 670	= ______	671
Lifecycle water cost per inhabitant:	671 / 14	= ______	672
Annual lifecycle water cost per inhabitant:	672 / 292	= ______	673

10.2 Assessment Tool in Computer Spreadsheet Format

With all of the algorithms determined in the worksheet, they could be used to construct a computer spreadsheet version of the assessment. This reduces the time taken to assess a dwelling, improves its accuracy, automates the interrelated links between criteria, and facilitates graphical representation of the outcomes. Default values are used to further increase the speed of an assessment.

At over 660 steps covering 28 pages, it is evident that in this format the tool is too cumbersome be used with ease. It is a specific intention that the tool can be used to vary aspects of the dwelling, such as the thickness of insulation, to determine to what extent this improves the overall performance of the dwelling. In a worksheet format, this would require recalculating the worksheet each time a change is made to determine the extent of any impact, which would clearly be a time consuming process. This can be overcome by using the algorithms of the tool to create a computer spreadsheet version of the worksheet.

The advantages of this are significant. Firstly, the assessment is much quicker and easier, as the user does not have to carry out any calculations. This will reduce the likelihood of mistakes due to human error, and increase the speed of assessing the design. Also, in the worksheet an equation might be broken down into several manageable stages, such as in determining the U-value of timber-framed elements, whilst accounting for the impact of the fractional area of timber and insulation. However, in a spreadsheet the equations can be much more complex, and therefore the number of steps in the total assessment can be minimised. It also becomes much easier to determine the benefits, or detrimental effects, of varying characteristics of the dwelling; the spreadsheet will automatically update all subsequent calculations if one is varied. Therefore it is possible to determine very quickly, for example, what the optimum insulation thickness would be to balance the additional embodied energy and reduced occupational energy consumption, or to determine the effect of varying the air tightness target on the annual energy consumption. The full benefit of the interrelationship between the criteria can therefore be utilised in maximising the performance of the dwelling, a principle ambition of the thesis.

Therefore, the decision was taken to convert the worksheet into a computer spreadsheet.[15] Microsoft Excel is a computer software programme for designing spreadsheets. It can automatically carry out calculations that are entered into it as equations, using data that is

[15] The software chosen for this is Microsoft Exel, Microsoft Office 98 - Macintosh Edition, Microsoft Corporation.

entered as variable. The following images show screen prints of parts of the completed spreadsheet for the 'urban house in paradise' assessment tool, as they appear on the computer monitor. Data is entered in the white boxes, and the results of the calculations are shown on the right hand side.

When the spreadsheet is opened for the first time, or for the first assessment of a dwelling, a certain number of generic default values will already be in place. An example would be the density and embodied energy of materials. This will save time in conducting an assessment by reducing the amount of data that needs to be determined from tables. However, these defaults are capable of being over-ridden if they are superseded by more specific values. Also, when the spreadsheet is opened a certain number of assumptions will be made, for example that the span of floor joists will be across the lesser dimension, the breadth, of the floor. As the user inputs data, these assumptions can also be left if they are correct, or simply over-ridden if not.

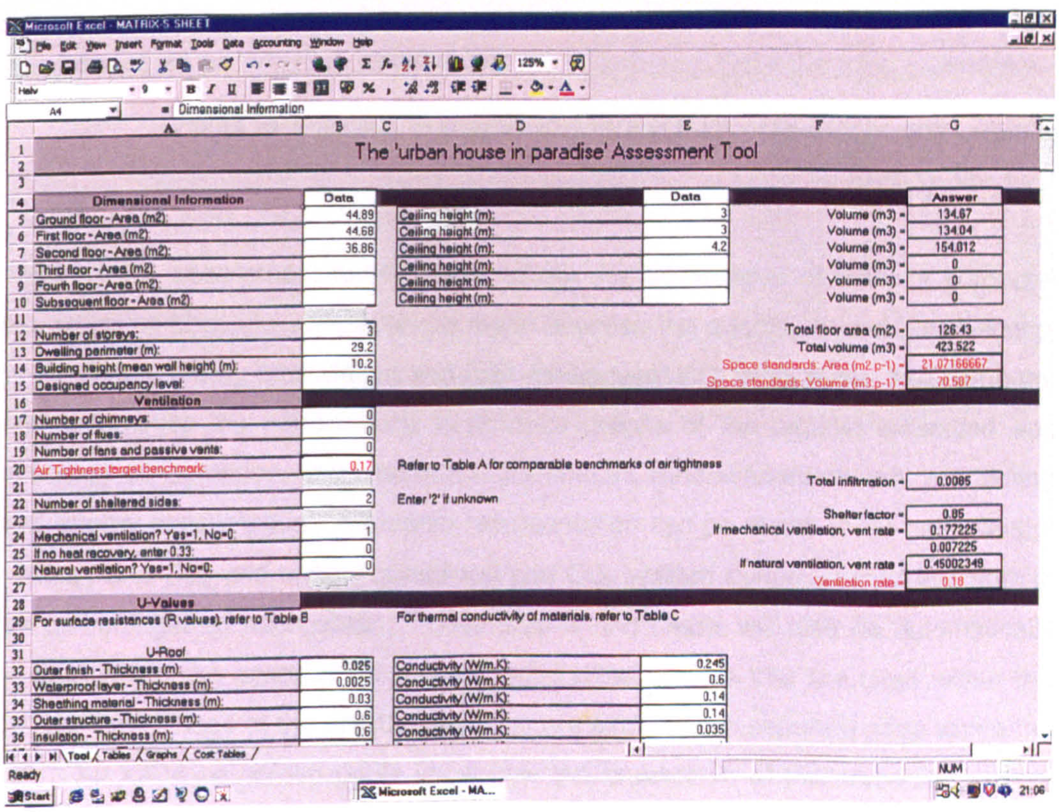


Figure 17: Opening page of the spreadsheet

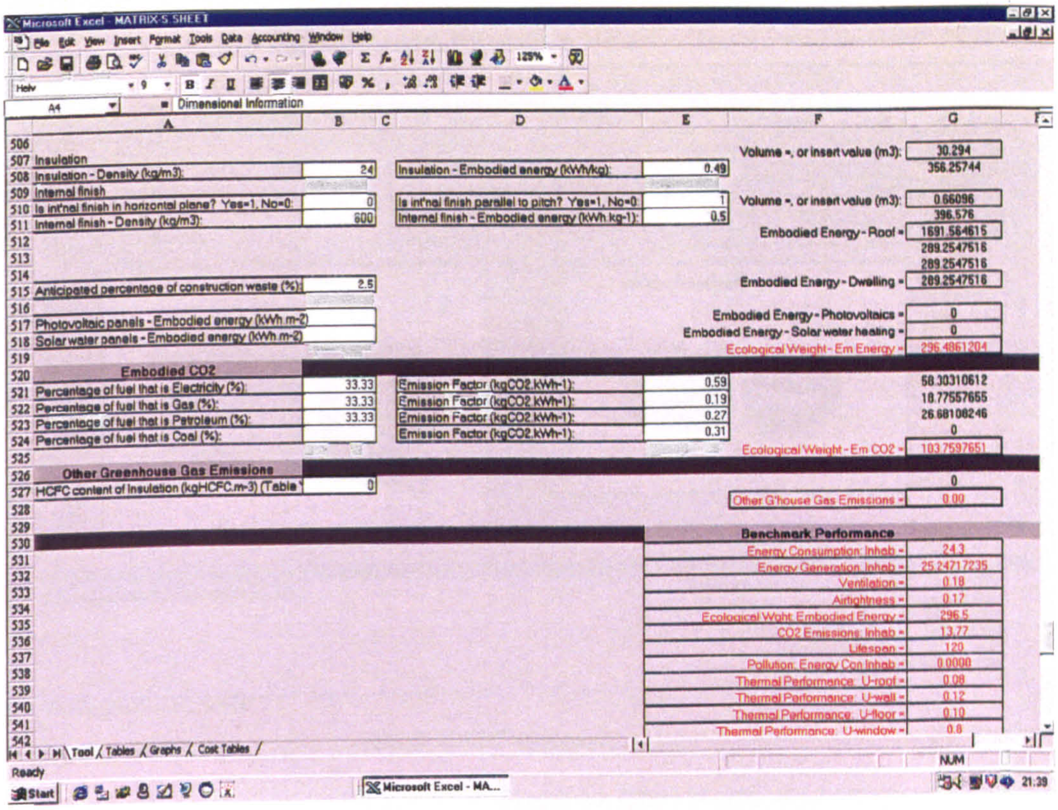


Figure 18: Embodied Energy benchmark and the benchmark performance profile

The last steps of the assessment further demonstrate the advantages of using a computer spreadsheet, when an absolute comparison is made between the quantity of embodied energy and energy consumed during inhabitation and their consequent CO_2 emissions. The computer can be used to analyse the performance to produce graphs of the relative embodied and operational energy consumption, and breakdown the amount various functions are contributing to the overall energy consumption. A graphic representation can be made of the quantities of embodied energy and CO_2 and energy consumed and CO_2 emitted during inhabitation, both in total and as percentages of each other. These graphs and charts will also be automatically updated as data within the assessment is changed. Tables of data that are used within the spreadsheet, and referenced at the appropriate step, are available on separate page within the spreadsheet. The following screen prints show how the breakdown of the embodied energy and the energy consumed during inhabitation appear on the computer monitor.

A print of the full spreadsheet as it would appear when first opened, with default values, is then shown over the following pages. A completed version for the dwelling designed in Drawn Studies 7 and 8 is located following their analysis in volume 2.

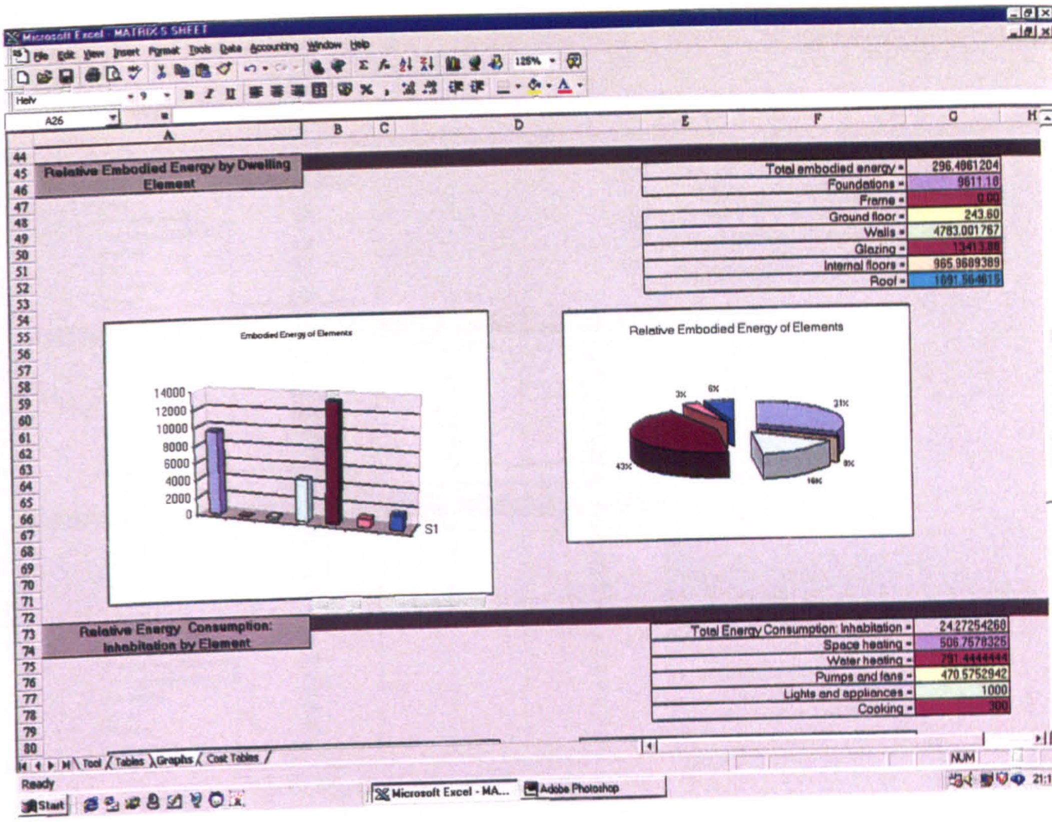


Figure 19: Chart of embodied energy by component

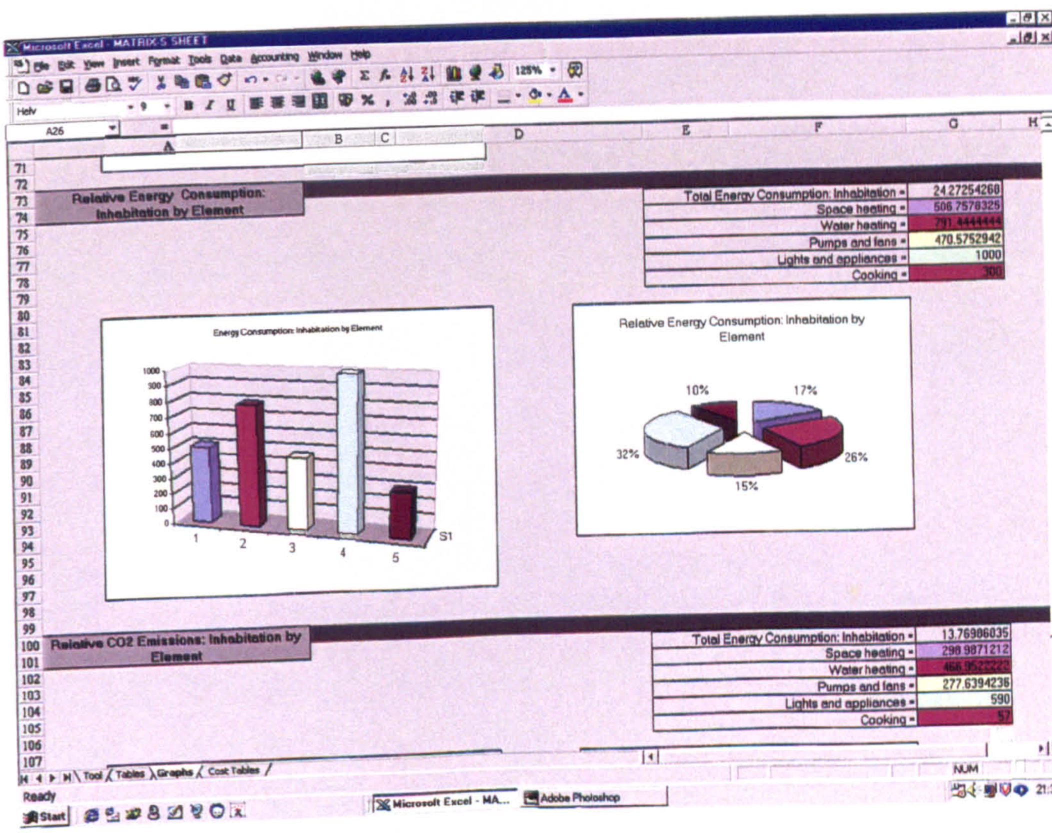


Figure 20: Chart of energy consumption during inhabitation by component

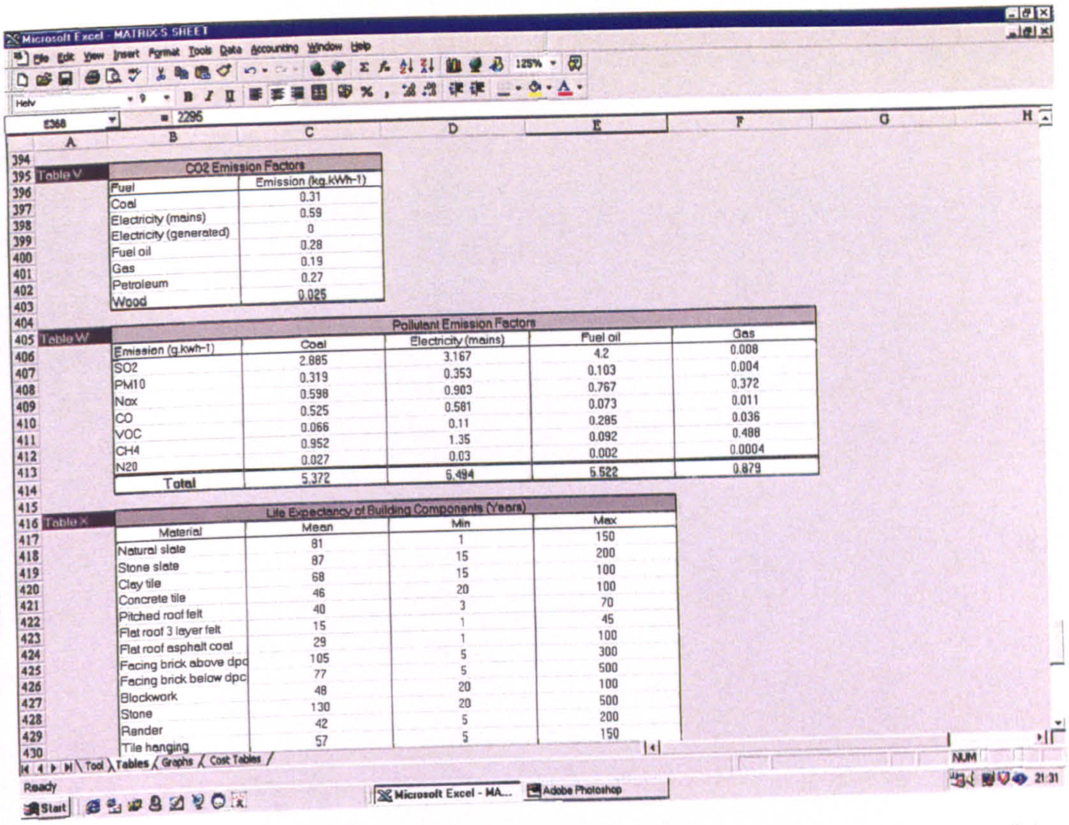


Table V

CO2 Emission Factors	
Fuel	Emission (kg.kWh-1)
Coal	0.31
Electricity (mains)	0.59
Electricity (generated)	0
Fuel oil	0.28
Gas	0.19
Petroleum	0.27
Wood	0.025

Table W

Pollutant Emission Factors				
Emission (g.kwh-1)	Coal	Electricity (mains)	Fuel oil	Gas
SO2	2.885	3.167	4.2	0.008
PM10	0.319	0.353	0.103	0.004
Nox	0.598	0.903	0.767	0.372
CO	0.525	0.581	0.073	0.011
VOC	0.066	0.11	0.285	0.036
CH4	0.952	1.35	0.092	0.488
N20	0.027	0.03	0.002	0.0004
Total	5.372	6.494	5.522	0.879

Table X

Life Expectancy of Building Components (Years)			
Material	Mean	Min	Max
Natural slate	81	1	150
Stone slate	87	15	200
Clay tile	68	15	100
Concrete tile	46	20	100
Pitched roof felt	40	3	70
Flat roof 3 layer felt	15	1	45
Flat roof asphalt coat	29	1	100
Facing brick above dpc	105	5	300
Facing brick below dpc	77	5	500
Blockwork	48	20	100
Stone	130	20	500
Render	42	5	200
Tile hanging	57	5	150

Figure 21: Tables of data are available on separate page within the spreadsheet

The Performance Benchmark Assessment Tool

Dimensional Information	Data		Data		Answer
Ground floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
First floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
Second floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
Third floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
Fourth floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
Subsequent floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
Number of storeys:				Total floor area (m2) =	0
Dwelling perimeter (m):				Total volume (m3) =	0
Building height (mean wall height) (m):				Space standards: Area (m2.p-1) =	#DIV/0!
Designed occupancy level:				Space standards: Volume (m3.p-1) =	#DIV/0!
Ventilation					
Number of chimneys:	0				
Number of flues:	0				
Number of fans and passive vents:	0				
Air Tightness target benchmark:	0.17	Refer to Table A for comparable benchmarks of air tightness		Total infiltration =	#DIV/0!
Number of sheltered sides:	2	Enter '2' if unknown		Shelter factor =	0.85
Mechanical ventilation? Yes=1, No=0:				If mechanical ventilation, vent rate =	#DIV/0!
If no heat recovery, enter 0.33:	0.33				#DIV/0!
Natural ventilation? Yes=1, No=0:	1			If natural ventilation, vent rate =	#DIV/0!
				Ventilation rate =	#DIV/0!

U-Values					
For surface resistances (R values), refer to Table B		For thermal conductivity of materials, refer to Table C			
U-Roof					
Outer finish - Thickness (m):	0.025	Conductivity (W/m.K):	0.245		
Waterproof layer - Thickness (m):	0.0025	Conductivity (W/m.K):	0.2		
Sheathing material - Thickness (m):	0	Conductivity (W/m.K):	1		
Outer structure - Thickness (m):	0.1	Conductivity (W/m.K):	0.14		
Insulation - Thickness (m):	0.2	Conductivity (W/m.K):	0.035		
Inner structure - Thickness (m):	0.1	Conductivity (W/m.K):	0.14		
Inner finish - Thickness (m):	0.012	Conductivity (W/m.K):	0.46		
Rso:	0.04				
Rcav:	0.17				
Rsi:	0.12				
Roof pitch (degrees):	55				
Is insulation laid in plane at pitch to ceiling? Yes=1, No=0:	0				
Is insulation laid in plane parallel to ceiling? Yes=1, No=0:	1				
Is roof solid construction? Yes=1, No=0:	0				0.138064399
Is roof timber construction? Yes=1, No=0:	1				0.237335931
Joist width (m):	0.05	Joist centre to centre (m):	0.6	U-Roof =	0.24
U-Wall					
Outer finish - Thickness (m):	0	Conductivity (W/m.K):	1		
Outer leaf - Thickness (m):	0.1	Conductivity (W/m.K):	1.21		
Sheathing material - Thickness (m):	0	Conductivity (W/m.K):	1		
Insulation - Thickness (m):	0.075	Conductivity (W/m.K):	0.036		
Inner structure - Thickness (m):	0.1	Conductivity (W/m.K):	0.19		
Inner finish - Thickness (m):	0.012	Conductivity (W/m.K):	0.46		
Rso:	0.05				
Rcav:	0.18				

Rsi:	0.12				0.325904800
Is wall solid construction? Yes=1, No=0:	1				0.453568758
Is wall timber frame construction? Yes=1, No=0:	0				
If timber frame, stud width (m):	0.05	Stud centre to centre (m):	0.6	U-Wall =	0.33
U-Ground					
Is floor a non-suspended floor? Yes=1, No=0:	1	Is floor a suspended floor? Yes=1, No=0:	0		
Are only 2 parallel edges exposed?	0	Are only 2 edges at right angles exposed?	0		
Does floor have only single exposed edge?	0				
Joist/beam (if applicable) - Depth (m):	0.25	Conductivity (W/m.K):	1		
Joist/beam - Width (m):	0.05	Joist/beam centre to centre (m):	0.6		
Screed - Depth (m)	0.05	Concrete slab - Depth (m):	0.3		
Hardcore - Depth (m):	0.3				
Deck or slab - Thickness (m):	0.3	Conductivity (W/m.K):	1.44	β =	#DIV/0!
Insulation - Thickness (m):	0.05	Conductivity (W/m.K):	0.035		#DIV/0!
External wall thickness (m):	0.3	Thermal conductivity of earth (W/m.K), or 1.4:	1.4	Corrected length =	0
Floor length (greater dimension) (m):		Floor breadth (lesser dimension) (m):		Correctedbreadth =	0
Rsi:	0.12				
				Unonsuspended =	#DIV/0!
				Ususpended=	#DIV/0!
				U-Ground =	#DIV/0!
U-Windows					
Independent manufacturer's U-value for glazing:	3.3			U-Window and Rooflight =	3.3
U-Doors					
Independent manufacturer's U-value for doors:	3.3			U-Door =	3.3
Heat Loss Parameters					
Roof area (excluding openings) (m2):					
External wall area (excluding openings) (m2):					
Party wall area (m2):					
Ground floor area (m2):	0				
Window area (m2):					
Rooflight area (m2):					
Door area (m2):					
Other element, area (m2):		U-value:		Total area of dwelling envelope =	0
				Ventilation heat loss =	#DIV/0!
				Heat loss coefficient =	#DIV/0!
				Heat loss parameter =	#DIV/0!
Water-heating Energy Requirements					
Is requirement on basis of consumption? Yes=1, No=0:	0	Is requirement on basis of floor area? Yes=1, No=0:	1		
On the basis of predicted consumption:					
Predicted hot water consumption (l.p-1.d-1) (Table O):	50	Temp difference between supply and heated (oC): 36 oC if header tank is within insulated envelope, otherwise 49 oC	49	Energy requirement =	0
				Distribution losses =	0
On the basis of floor area:					
Hot water energy requirement (Table O1):		Distribution losses (Table O1):			
Hot water storage volume (litres):		Storage loss factor (Table E):		Actual energy requirement =	0
Primary circuit losses (Table F):		Efficiency of water heater (Table G1 or G2): Value should be adjusted by amount shown in 'efficiency adjustment' column in Table G3 and G5 where appropriate.		Actual distribution losses =	0
				Energy for water heating =	#DIV/0!
				Heat gains from water heating =	0
Internal Gains					
Are gains on basis of actual values? Yes=1, No=0:	0	Are gains on basis of floor area? Yes=1, No=0:	1		
On basis of actual values:					
Anticipated occupancy per week (hours), 90 or:	90			Metabolic gains =	0
Mean wattage of light bulbs (W), e.g. 13.5 or 80:	13.5			Lighting gains =	0

Total annual appliance consumption (kWh.a-1) (Table R)				Appliance gains =	0
Total annual cooking consumption (kWh.a-1) (Table R)				Cooking gains =	0
On basis of floor area:					
Lights, appliances, cooking and metabolic (W) (Table H):				Actual met, light, app and cook gains =	0
Additional gains (W) (Table H):				Water heat gains =	0
				Total internal incidental gains =	0

Solar Gains

For solar flux, refer to Table I

North facing - Area (m2):		Solar flux (W.m-2):			
North east facing - Area (m2):		Solar flux (W.m-2):			
East facing - Area (m2):		Solar flux (W.m-2):			
South east facing - Area (m2):		Solar flux (W.m-2):			
South facing - Area (m2):		Solar flux (W.m-2):			
South west facing - Area (m2):		Solar flux (W.m-2):			
West facing (m2):		Solar flux (W.m-2):			
North west facing - Area (m2):		Solar flux (W.m-2):			
Rooflights - Area (m2):		Solar flux (W.m-2):			
For solar access factor, refer to Table J; for new dwellings, if unknown, enter 1				Solar gains =	0
Solar access factor:	1			Total gains =	0
For Utilisation Factor, refer to Table K				Gains/loss ratio =	#DIV/0!
Utilisation factor:				Useful gains =	0

Mean Internal Temperature

Mean internal temperature of living area (Table L):		Temperature adjustment (Table G5, if applicable):	0		
Heating system responsiveness, R (Table G1 or G4):	1				
Temperature difference between zones (Table M):				Mean internal temperature =	#DIV/0!
Living room area (m2):					

Degree Days

				Base temperature =	#DIV/0!
Degree days (Table N):				Useful energy requirement =	#DIV/0!

Water Consumption

Refer to Table O to determine predicted water consumption

Predicted consumption benchmark (litre/p/day):	160				
Rainwater storage (litres):				Storage ratio =	#DIV/0!
If storage ratio <1, enter value; if not, enter 1:	#DIV/0!				#DIV/0!
Area of rainwater collection surfaces (m2):	0	Rainfall (mm.a-1) (Table P):	819	Potable consumption =	#DIV/0!
				Rainwater consumption =	#DIV/0!

Energy Consumption - Inhabitation

Space and Water heating energy consumption:

Is heating by an individual system? Yes=1, No=0:	1	Is heating by a community system? Yes=1, No=0:	0		
		Does community heating have CHP? Yes=1, No=0:	0		
If by an individual system:					
Fraction of heat from secondary system (Table Q):				Primary space heating =	#DIV/0!
Efficiency of primary heating system (%):		Efficiency of secondary heating system (%):	1	Secondary space heating =	#DIV/0!

Values for efficiency of system from Table G1 or G2, adjusted by amount shown in 'efficiency adjustment' column in Table G3 and G5 where appropriate.

If by a community system:					
Overall system efficiency:	100	Fraction of heat from CHP unit:		Space heating from CHP =	#DIV/0!
Distribution Loss Factor (Table O2):	1.1	Fraction taken from operational records or design specification		Space heating from boilers =	#DIV/0!

				Primary space heating =	#DIV/0!
				Secondary space heating =	#DIV/0!
				Water heating =	#DIV/0!
Pumps and Fans consumption:					
Number of central heating pumps:		Number of boilers with fan assisted flues:			
Warm air heating fans? Yes=1, No=0:		Full mechanical ventilation? Yes=1, No=0:		Pumps and fans =	0
Lighting and Appliance consumption:					
Is consumption based on actual values? Yes=1, No=0:	0	Is consumption based on floor area? Yes=1, No=0:	1		
If on basis of actual values:					
Mean wattage of light bulbs (W), e.g. 13.5 or 80:	13.5			Consumption =	0
Total consumption of appliances (kWh.a-1) (Table R):	0			Consumption =	0
On basis of floor area:					
Lights and appliances (Table S):				Lights and appliances =	0
Cooking consumption:					
Total Cooking (kWh.a-1) (Table T):				Cooking =	0
				Energy Consumption: Inhab =	#DIV/0!

Energy Generation					
Photovoltaic Panels					
Annual solar energy availability, (kWh.m-2.a-1) :	1000	Efficiency of panel (%), or 19%:	19		
Refer to Table U for value by location, or 1000 kWh.m-2.a-1					
Area of photovoltaic array (m2):				Generation per annum =	0
Solar Water Panels					
Area of panel (m2):				Generation per annum =	0
Wind Turbines					
Average monthly windspeed (m.s-1) (Table U1):		Generator hub height (m):			
Roughness length (m), 0.4 m for urban areas:	0.4			Windspeed at hub height =	#NUM!
Annual energy yield:		Number of turbines:		Generation per annum =	0
Other sources (kWh per annum):				Generation per annum =	0
				Energy Generation: Inhab =	#DIV/0!

CO2 + Pollution Emissions - Inhabitation					
For CO2 emission factors, refer to Table V		For pollution emission factors, refer to Table W			
For individual heating systems:					
Primary space heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Gross CO2 emission =	#DIV/0!
Secondary space heating - CO2 emission factor:		Pollution emission factor:		Net CO2 emission =	#DIV/0!
Water Heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Gross Pollution Emissions - Inhab =	#DIV/0!
				Net Pollution Emissions - Inhab =	#DIV/0!
For community systems without CHP:					
Primary space heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Gross CO2 emission =	#DIV/0!
Water Heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Net CO2 emission =	#DIV/0!
				Gross Pollution Emissions - Inhab =	#DIV/0!
				Net Pollution Emissions - Inhab =	#DIV/0!
				CO2 emission factor for heat =	0.045
For community systems with CHP:				Pollution emissions factor of heat =	0
Electrical efficiency of CHP unit, 0.25 or:	0.25	Heat efficiency of CHP unit, 0.50 or:	0.5	Gross CO2 emission =	#DIV/0!
CHP fuel - CO2 emission factor:	0.21	CHP fuel - pollution emission factor:	0.879	Net CO2 emission =	#DIV/0!
Electricity CO2 emission factor:	0.75	Electricity - pollution emission factor:	6.494	Gross Pollution Emissions - Inhab =	#DIV/0!
Boiler - CO2 emission factor:	0.21	Boiler - pollution emission factor:	0.879	Net Pollution Emissions - Inhab =	#DIV/0!

To be completed for all dwellings:					
Pumps and fans - CO2 emission factor:	0.75	Pollution emission factor:	6.494		
Lights and appliances - CO2 emission factor:	0.75	Pollution emission factor:	6.494		
Cooking - CO2 emission factor:	0.21	Pollution emission factor:	0.879		
Area of green space (m2):					
				Gross CO2 emission =	#DIV/0!
				Net CO2 emission =	#DIV/0!
				Gross Pollution Emissions - Inhab =	#DIV/0!
				Net Pollution Emissions - Inhab =	#DIV/0!
				CO2 Emmision: Inhabitation =	#DIV/0!
				Pollution Emissions - Inhab =	#DIV/0!

Lifespan and Replacement Ratios

For life expectancy of building components, refer to Table X

Lifespan benchmark (years):	60			
Roof external finish - Life span (years):	60	1.00	Replacement ratio =	1
Roof structure - Life span (years):	120	0.50	Replacement ratio =	1
Roof insulation - Life span (years):	120	0.50	Replacement ratio =	1
Roof internal finish - Life span (years):	73	0.82	Replacement ratio =	1
Wall external finish - Life span (years):	30	2.00	Replacement ratio =	2
Wall structure - Life span (years):	120	0.50	Replacement ratio =	1
Wall insulation - Life span (years):	120	0.50	Replacement ratio =	1
Wall internal finish - Life span (years):	73	0.82	Replacement ratio =	1
Window and rooflight - Life span (years):	60	1.00	Replacement ratio =	1
Floor finish - Life span (years):	120	0.50	Replacement ratio =	1
Floor structure - Life span (years):	120	0.50	Replacement ratio =	1
Floor insulation - Life span (years):	120	0.50	Replacement ratio =	1
Internal Staircases - Life span (years):	78	0.77	Replacement ratio =	1
Photovoltaic panels - Life span (years):	25	2.40	Replacement ratio =	3
Solar water panels - Life span (years):	25	2.40	Replacement ratio =	3

Embodied Energy

For densities of materials, refer to Table C

For embodied energy of materials, refer to Table C

Is dwelling a house - Yes=1, No=0:	1				
Is dwelling a flat or apartment - Yes=1, No=0:	0	If flat, total number of dwellings within building:	1		
Foundations					
If strip/trench footing - Yes=1, No=0:	1				
Are there internal foundations - Yes=1, No=0:	0	Length of internal foundations (m):	0		
Strip/trench depth (m):	0.25	Strip/trench width (m):	0.5	Volume =, or insert value (m3):	0.00
Strip/trench - Density (kg/m3):	2600	Strip/trench - Embodied energy (kWh/kg):	0.2		0.00
Wall width below ground (combined if twin leaf):	0.2	Depth of wall below ground (m):	0.8	Volume =, or insert value (m3):	0.00
Wall - Density (kg/m3):	1200	Wall - Embodied energy (kWh/kg):	0.5		0.00
Cavity width (m):	0.1	Depth of cavity fill (m):	2.3	Volume =, or insert value (m3):	0.00
Cavity fill - Density (kg/m3):	500	Cavity fill - Embodied energy (kWh/kg):	0.01		0.00
					0.00
If pile foundation - Yes=1, No=0:	0				
Number of piles:		Cross-sectional area of pile (m2):			
Depth of piles (m):				Volume =, or insert value (m3):	0.00
Pile - Density (kg/m3):	2600	Pile - Embodied energy (kWh/kg):	0.2		0.00
Number of pile caps:		Cross-sectional area of pile caps (m2):			
Depth of pile caps (m):				Volume =, or insert value (m3):	0.00
Pile cap - Density (kg/m3):	2600	Pile cap - Embodied energy (kWh/kg):	0.2		0.00
Depth of ground beams (m):	0.6	Width of ground beams (m):	0.3		
Length of ground beams (m):				Volume =, or insert value (m3):	0.00
Ground beam - Density (kg/m3):	2600	Ground beam - Embodied energy (kWh/kg):	0.2		0.00
					0.00

If pad foundation - Yes=1, No=0:	0				
Number of pads:		Pad length (m):		Volume =, or insert value (m3):	0.00
Pad width (m):		Pad depth (m)			0.00
Pad - Density (kg/m3):	2600	Pad - Embodied energy (kWh/kg):	0.2		
Depth of ground beams (m):	0.6	Width of ground beams (m):	0.3	Volume =, or insert value (m3):	0.00
Length of ground beams (m)					0.00
Ground beam - Density (kg/m3):	0	Ground beam - Embodied energy (kWh/kg):	0		0.00
				Embodied Energy - Foundations =	0.00
Basement					
Perimeter, as ground floor or other (m2):	0	Depth (m):	2.3		
Wall width (m):	0			Volume =, or insert value (m3):	0.00
Note: *Enter zero if accounted for in depth of strip foundation walls*					
Wall - Density (kg/m3):	0	Wall - Embodied energy (kWh/kg):	0		0.00
Tanking thickness (m)				Volume =, or insert value (m3):	0.00
Tanking - Density (kg/m3):	300	Tanking - Embodied energy (kWh/kg):	12		0.00
Wall insulation thickness (m):		Wall insulatiopn depth (m)		Volume =, or insert value (m3):	0.00
Wall insulation - Density (kg/m3):	24	Wall Insulation - Embodied energy (kWh/kg):	0.49		0.00
Area of floor, as ground floor or other (m2):	0	Depth of floor (m):	0.25	Volume =, or insert value (m3):	0.00
Floor - Density (kg/m3):	2600	Floor - Embodied energy (kWh/kg):	0.2		0.00
Floor insulation depth (m):				Volume =, or insert value (m3):	0.00
Floor insulation - Density (kg/m3):	24	Floor insulation - Embodied energy (kWh/kg):	0.49		0.00
Hardcore depth (m):	0.3			Volume =, or insert value (m3):	0.00
Note: *Enter zero if to be accounted for in ground floor analysis*					
Hardcore - Density (kg/m3):	500	Hardcore - Embodied energy (kWh/kg):	0.1		0.00
				Embodied Energy - Basement =	0.00
Frame					
Number of columns:	0	Cross-sectional area of columns (m2):			
Column height (m):				Volume =, or insert value (m3):	0.00
Column - Density (kg/m3):	0	Column - Embodied energy (kWh/kg):	0		0.00
Number of beams per floor:		Cross-sectional area of beams (m2):			
Beam length (m):				Volume =, or insert value (m3):	0.00
Beam - Density (kg/m3):	0	Beam - Embodied energy (kWh/kg):	0		0.00
				Embodied Energy - Frame =	0.00
Ground Floor					
Is floor timber construction? Yes=1, No=0:	1	Is floor concrte slab? Yes=1, No=0:	0		
Is floor concrte beam/block? Yes=1, No=0:	0				
If timber:					
Floor dimension perpendicular to span (m):		Length of span (m):			
Number of joists = actual, or:	1	Number of noggins = actual, or:	0	Volume =, or insert value (m3):	0.00
Area of noggin cross-section (m2):	0.0026				0.00
Timber - Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0.00
Insulation					0.00
Insulation - Density (kg/m3):	24	Insulation - Embodied energy (kWh/kg):	0.49		0.00
If concrete slab:					
Screed				Volume =, or insert value (m3):	0.00
Screed - Density (kg/m3):	800	Screed - Embodied energy (kWh/kg):	0.6		0.00
Concrete				Volume =, or insert value (m3):	0.00
Concrete - Density (kg/m3):	2600	Concrete - Embodied energy (kWh/kg):	0.2		0.00
Insulation				Volume =, or insert value (m3):	0.00
Insulation - Density (kg/m3):	25	Insulation - Embodied energy (kWh/kg):	0.49		0.00
Hardcore				Volume =, or insert value (m3):	0.00
Hardcore - Density (kg/m3):	500	Hardcore - Embodied energy (kWh/kg):	0.1		0.00
					0.00
If concrete beam and block:					
Floor dimension perpendicular to span (m):		Length of span (m):			
Beam spacing (m):	0.6	Number of beams = actual, or:	1		
Area of beam cross-section (m2):	0.36	Length of block (mean) (m):	0.6		

If pad foundation - Yes=1, No=0:	0				
Number of pads:		Pad length (m):		Volume =, or insert value (m3):	0.00
Pad width (m):		Pad depth (m)			0.00
Pad - Density (kg/m3):	2600	Pad - Embodied energy (kWh/kg):	0.2		
Depth of ground beams (m):	0.6	Width of ground beams (m):	0.3	Volume =, or insert value (m3):	0.00
Length of ground beams (m)					0.00
Ground beam - Density (kg/m3):	0	Ground beam - Embodied energy (kWh/kg):	0		0.00
				Embodied Energy - Foundations =	0.00
Basement					
Perimeter, as ground floor or other (m2):	0	Depth (m):	2.3	Volume =, or insert value (m3):	0.00
Wall width (m):	0				
Note: *Enter zero if accounted for in depth of strip foundation walls*					0.00
Wall - Density (kg/m3):	0	Wall - Embodied energy (kWh/kg):	0	Volume =, or insert value (m3):	0.00
Tanking thickness (m)					0.00
Tanking - Density (kg/m3):	300	Tanking - Embodied energy (kWh/kg):	12	Volume =, or insert value (m3):	0.00
Wall insulation thickness (m):		Wall insulatiopn depth (m)			0.00
Wall insulation - Density (kg/m3):	24	Wall Insulation - Embodied energy (kWh/kg):	0.49	Volume =, or insert value (m3):	0.00
Area of floor, as ground floor or other (m2):	0	Depth of floor (m):	0.25		0.00
Floor - Density (kg/m3):	2600	Floor - Embodied energy (kWh/kg):	0.2	Volume =, or insert value (m3):	0.00
Floor insulation depth (m):					0.00
Floor insulation - Density (kg/m3):	24	Floor insulation - Embodied energy (kWh/kg):	0.49	Volume =, or insert value (m3):	0.00
Hardcore depth (m):	0.3				
Note: *Enter zero if to be accounted for in ground floor analysis*					0.00
Hardcore - Density (kg/m3):	500	Hardcore - Embodied energy (kWh/kg):	0.1	Embodied Energy - Basement =	0.00
Frame					
Number of columns:	0	Cross-sectional area of columns (m2):		Volume =, or insert value (m3):	0.00
Column height (m):					0.00
Column - Density (kg/m3):	0	Column - Embodied energy (kWh/kg):	0		
Number of beams per floor:		Cross-sectional area of beams (m2):		Volume =, or insert value (m3):	0.00
Beam length (m):					0.00
Beam - Density (kg/m3):	0	Beam - Embodied energy (kWh/kg):	0	Embodied Energy - Frame =	0.00
Ground Floor					
Is floor timber construction? Yes=1, No=0:	1	Is floor concrte slab? Yes=1, No=0:	0		
Is floor concrte beam/block? Yes=1, No=0:	0				
If timber:					
Floor dimension perpendicular to span (m):		Length of span (m):			
Number of joists = actual, or:	1	Number of noggins = actual, or:	0	Volume =, or insert value (m3):	0.00
Area of noggin cross-section (m2):	0.0026				0.00
Timber - Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0.00
Insulation					0.00
Insulation - Density (kg/m3):	24	Insulation - Embodied energy (kWh/kg):	0.49		0.00
If concrete slab:				Volume =, or insert value (m3):	0.00
Screed					0.00
Screed - Density (kg/m3):	800	Screed - Embodied energy (kWh/kg):	0.6	Volume =, or insert value (m3):	0.00
Concrete					0.00
Concrete - Density (kg/m3):	2600	Concrete - Embodied energy (kWh/kg):	0.2	Volume =, or insert value (m3):	0.00
Insulation					0.00
Insulation - Density (kg/m3):	25	Insulation - Embodied energy (kWh/kg):	0.49	Volume =, or insert value (m3):	0.00
Hardcore					0.00
Hardcore - Density (kg/m3):	500	Hardcore - Embodied energy (kWh/kg):	0.1		0.00
If concrete beam and block:					
Floor dimension perpendicular to span (m):		Length of span (m):			
Beam spacing (m):	0.6	Number of beams = actual, or:	1		
Area of beam cross-section (m2):	0.36	Length of block (mean) (m):	0.6		

Width of block (m):	0.3	Number of blocks = actual, or:	0.0	Volume =, or insert value (m3):	0.00
Beams					0
Beam - Density (kg/m3):	2600	Beam - Embodied energy (kWh/kg):	0.2	Volume =, or insert value (m3):	0
Blocks					0
Block - Density (kg/m3):	800	Block - Embodied energy (kWh/kg):	1.2	Volume =, or insert value (m3):	0.00
Screed depth (m):	0.05				0
Screed - Density (kg/m3):	800	Screed - Embodied energy (kWh/kg):	0.6	Volume =, or insert value (m3):	0
Insulation					0
Insulation - Density (kg/m3):	25	Insulation - Embodied energy (kWh/kg):	0.49		0.00
				Embodied Energy - Gnd Floor =	0.00
External Walls					
External wall length (m):	16.9				
External Walls - Masonry					
External finish				Volume =, or insert value (m3):	0.00
External finish - Density (kg/m3):		External finish - Embodied energy (kWh/kg):			0.00
Outer leaf				Volume =, or insert value (m3):	0.00
Outer leaf - Density (kg/m3):	1750	Outer leaf - Embodied energy (kWh/kg):	1.2		0.00
Insulation				Volume =, or insert value (m3):	0.00
Insulation - Density (kg/m3):	40	Insulation - Embodied energy (kWh/kg):	0.49		0.00
Inner leaf				Volume =, or insert value (m3):	0.00
Inner leaf - Density (kg/m3):	1200	Inner leaf - Embodied energy (kWh/kg):	0.5		0.00
Internal finish				Volume =, or insert value (m3):	0.00
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5		0.00
				Embodied energy =	0.00
External Walls - Timber Frame				Volume =, or insert value (m3):	0.00
External finish					0.00
External finish - Density (kg/m3):	0	External finish - Embodied energy (kWh/kg):	1	Volume =, or insert value (m3):	0.00
Outer leaf					0.00
Outer leaf - Density (kg/m3):	700	Outer leaf - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0.00
Sheathing ply					0.00
Sheathing ply - Density (kg/m3):	700	Sheathing ply - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0.00
Insulation					0.00
Insulation - Density (kg/m3):	40	Insulation - Embodied energy (kWh/kg):	0.49		
Stud width (m):	0.05	Stud depth (m):	0.1		
Sole plate width (m):	0.1	Sole plate depth (m):	0.05		
Head plate width (m):	0.1	Head plate depth (m):	0.05		
Header Joist width (m):	0.1	Hearder Joist depth (m):	0.25	Volume =, or insert value (m3):	0.00
Inner leaf					0.00
Inner leaf - Density (kg/m3):	700	Inner leaf - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0.00
Internal finish					0
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5	Embodied energy =	0.00
Party Walls - Masonry				Volume =, or insert value (m3):	0.00
Insulation - Thickness (m):					0.00
Insulation - Density (kg/m3):	40	Insulation - Embodied energy (kWh/kg):	0.49	Volume =, or insert value (m3):	0.00
Inner leaf - Thickness (m):	0.1				0
Inner leaf - Density (kg/m3):	1200	Inner leaf - Embodied energy (kWh/kg):	0.5	Volume =, or insert value (m3):	0
Internal finish - Thickness (m):	0.012				0
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5	Embodied energy =	0.00
Party Walls - Timber Frame				Volume =, or insert value (m3):	0
Sheathing ply					0
Sheathing ply - Density (kg/m3):	700	Sheathing ply - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0
Insulation - Thickness (m):					0
Insulation - Density (kg/m3):	40	Insulation - Embodied energy (kWh/kg):	0.49		
Stud width (m):	0.05	Stud depth (m):	0.1		
Sole plate width (m):	0.1	Sole plate depth (m):	0.05		
Head plate width (m):	0.1	Head plate depth (m):	0.05		
Header Joist width (m):	0.1	Hearder Joist depth (m):	0.25		

Inner leaf - Thickness (m):	0.1			Volume =, or insert value (m3):	0.00
Inner leaf - Density (kg/m3):	700	Inner leaf - Embodied energy (kWh/kg):	0.1		0
Internal finish - Thickness (m):	0.012			Volume =, or insert value (m3):	0
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5		0
				Embodied energy =	0.00
Internal Load Bearing Walls					
Length of internal loadbearing walls (m):	0	Height of internal loadbearing walls (m):	6		
Masonry					
Structure - Thickness (m):	0.1			Volume =, or insert value (m3):	0.00
Structure - Density (kg.m-3):	1200	Structure - Embodied Energy (kWh/kg):	0.5		0
Finish - Thickness (m):	0.012			Volume =, or insert value (m3):	0.00
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5		0
				Embodied Energy =	0.00
Timber Frame				Volume =, or insert value (m3):	0.00
Sheathing ply					0
Sheathing ply - Density (kg/m3):	700	Sheathing ply - Embodied energy (kWh/kg):	0.1		
Stud width (m):	0.05	Stud depth (m):	0.1		
Sole plate width (m):	0.1	Sole plate depth (m):	0.05		
Head plate width (m):	0.1	Head plate depth (m):	0.05		
Header Joist width (m):	0.1	Hearder Joist depth (m):	0.25	Volume =, or insert value (m3):	#DIV/0!
Structure - Thickness (m):	0.1				#DIV/0!
Inner leaf - Density (kg/m3):	700	Inner leaf - Density (kg/m3):	0.1	Volume =, or insert value (m3):	0
Internal finish - Thickness (m):	0.012				0
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5	Embodied energy =	#DIV/0!
				Embodied Energy - Walls =	#DIV/0!
Windows and Rooflights				Volume =, or insert value (m3):	0
Level of glazing:	3	Pane tickness (m):	0.004		0
Glass - Density (kg/m3):	2500	Glass - Embodied energy (kWh/kg):	6	Volume =, or insert value (m3):	0
Perimeter of windows and rooflights, inc midrails (m):		Area of frame cross section (m2):	0.005		0
Frame - Density (kg/m3):	700	Frame - Embodied energy (kWh/kg):	0.1	Embodied Energy - Glazing =	0
Internal Floors					
Are floors timber construction? Yes=1, No=0:	1	Are floors concrte beam/block? Yes=1, No=0:	0		
If timber:					
First floor - dimension perpendicular to span (m):		First floor - length of span (m):			
Joist spacing (m):	0.6	Number of joists = actual, or:	1		
Joist depth (m):	0.25	Joist width (m):	0.05		
Area of noggin cross-section (m2):	0.0026	Number of noggins = actual, or:	0	Volume =, or insert value (m3):	#DIV/0!
Floorboard thickness (m):	0.019	Total area of internal floors (m2):	0		#DIV/0!
Timber Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0
Soffit finish thickness (m)	0.015				0
Soffit finish - Density (kg/m3):	600	Soffit finish - Embodied energy (kWh/kg):	0.5	Embodied energy =	#DIV/0!
If concrete beam and block:					
First floor - dimension perpendicular to span (m):	0	First floor - length of span (m):	0		
Beam spacing (m):	0.9	Number of beams = actual, or:	1		
Area of beam cross-section (m2):	0.36	Length of block (mean) (m):	0.9		
Width of block (m):	0.3	Number of blocks = actual, or:	0	Volume =, or insert value (m3):	0
					0
Beam - Density (kg/m3):	1200	Beam - Embodied energy (kWh/kg):	600	Volume =, or insert value (m3):	0
					0
Block - Density (kg/m3):	800	Block - Embodied energy (kWh/kg):	600	Volume =, or insert value (m3):	0
Screed depth (m):	0.05				0
Screed - Density (kg/m3):	800	Screed - Embodied energy (kWh/kg):	0.6	Volume =, or insert value (m3):	0
Soffit finish thickness (m)	0.015				0
Soffit finish - Density (kg/m3):	600	Soffit finish - Embodied energy (kWh/kg):	0.5	Embodied Energy =	#DIV/0!

Total area of internal floors (m2):	0				
				Embodied Energy - Int'l Floors =	#DIV/0!
Internal Staircases					
Are stairs other than precast concrete? Yes=1, No=0	1	Are internal stairs precast concrete? Yes=1, No=0	0		
Number of flights	-1				
For stairs other than precast concrete					
Number of treads		Number of risers	1		
Tread length (m):		Tread width (m):			
Tread thickness (m):				Volume =, or insert value (m3):	0
Tread - Density (kg/m3):	700	Tread - Embodied energy (kWh/kg):	0.1		0
Riser height (m):		Riser width (m):			
Riser thickness (m):				Volume =, or insert value (m3):	0
Riser - Density (kg/m3):	700	Riser - Embodied energy (kWh/kg):	0.1		0
Staircase length (m):					
String depth (m):		String thickness (m):		Volume =, or insert value (m3):	0
String - Density (kg/m3):	700	String - Embodied energy (kWh/kg):	0.1		0
				Embodied energy =	0
Precast concrete stairs					
Staircase length (m):		Staircase width (m):			
Mean staicase slab thckness (m):				Volume =, or insert value (m3):	0
Staircase - Density (kg/m3):		Staircase - Embodied energy (kWh/kg):			0
				Embodied energy =	0
				Embodied Energy - Int'l Stairs =	0
Roof					
Area of roof (excluding openings) (m2):	0	Area, parallel to ceiling plane (m2):	0		
Roof length (m):					
Area per unit of outer finsih (tile or sheet) (m2):	0.142	Area of overlap of outer finish (m2/unit):	0.03795	Volume =, or insert value (m3):	0
Outer finish - Density (kg/m3):	700	Outer finish - Embodied energy (kWh/kg):	0.28		0
Waterproof Layer - Density (kg/m3):	400	Waterproof Layer - Embodied energy (kWh/kg):	4.5		0
Is structure timber? Yes=1, No=0:	1	Is structure steel? Yes=1, No=0:	0		
If timber:					
Volume per truss or joist and firring (m3):	0.15	Number of trusses or joists, actual or:	1		
Volume per batten (m3):	0.006	Number of battens:		Volume =, or insert value (m3):	0.15
Timber Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1		10.5
If steel:					
Area of beam cross-section (m2):		Beam length (m):			
Beam spacing (m):		Number of beams = actual, or:	0	Volume =, or insert value (m3):	0
Beam - Density (kg/m3):	7900	Beam - Embodied energy (kWh/kg):	10		0
Insulation				Volume =, or insert value (m3):	0
Insulation - Density (kg/m3):	24	Insulation - Embodied energy (kWh/kg):	0.49		0
Internal finish					
Is internal finish in horizontal plane? Yes=1, No=0:	0	Is internal finish parallel to pitch? Yes=1, No=0:	1	Volume =, or insert value (m3):	0
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh.kg-1):	0.5		0
				Embodied Energy - Roof =	10.5
					#DIV/0!
					#DIV/0!
Anticipated percentage of construction waste (%):	10	Typical practice = 10, Best practice = 2.5		Embodied Energy - Dwelling =	#DIV/0!
Photovoltaic panels - Embodied energy (kWh.m-2)				Embodied Energy - Photovoltaics =	0
Solar water panels - Embodied energy (kWh.m-2)				Embodied Energy - Solar water heating =	0
				Ecological Weight - Em Energy =	#DIV/0!
Embodied CO2					
Percentage of fuel that is Electricity (%):	33.33	Emission Factor (kgCO2.kWh-1):	0.75		#DIV/0!
Percentage of fuel that is Gas (%):	33.33	Emission Factor (kgCO2.kWh-1):	0.21		#DIV/0!
Percentage of fuel that is Petroleum (%):	33.33	Emission Factor (kgCO2.kWh-1):	0.27		#DIV/0!
Percentage of fuel that is Coal (%):		Emission Factor (kgCO2.kWh-1):	0.31		#DIV/0!

Other Greenhouse Gas Emissions

HCFC content of Insulation (kgHCFC.m-3) (Table Y):	0

Ecological Weight - Em CO2 =	#DIV/0!
	0
Other G'house Gas Emissions =	0.00

Benchmark Performance

Energy Consumption: Inhab =	#DIV/0!
Energy Generation: Inhab =	#DIV/0!
Ventilation =	#DIV/0!
Airtightness =	0.17
Ecological Wght: Embodied Energy =	#DIV/0!
CO2 Emissions: Inhab =	#DIV/0!
Lifespan =	60
Pollution: Energy Con Inhab =	#DIV/0!
Thermal Performance: U-roof =	0.24
Thermal Performance: U-wall =	0.33
Thermal Performance: U-floor =	#DIV/0!
Thermal Performance: U-window =	3.3
Thermal Performance: U-door =	3.3
Ecological Wght: Embodied CO2 =	#DIV/0!
Other Greenhouse Gas Emissions =	0.00
Water Consumption: Total =	160.0
Water Consumption: Potable =	#DIV/0!

Scoring

Energy Consumption: Inhab =	#DIV/0!
Energy Generation: Inhab =	#DIV/0!
Ventilation =	#DIV/0!
Airtightness =	0.159
Ecological Weight: Embodied Energy =	#DIV/0!
CO2 Emissions: Inhab =	#DIV/0!
Lifespan =	0.063
Pollution: Energy Con Inhab =	#DIV/0!
Thermal Performance: U-roof =	#DIV/0!
Thermal Performance: U-wall =	#DIV/0!
Thermal Performance: U-floor =	#DIV/0!
Thermal Performance: U-window =	#DIV/0!
Thermal Performance: U-door =	#DIV/0!
Ecological Weight: Embodied CO2 =	#DIV/0!
Other Greenhouse Gas Emissions =	0.034
Water Consumption: Total =	0.00418
Water Consumption: Potable =	#DIV/0!

Score = #DIV/0!

Life Cycle Energy Consumption and Cost

Embodied Energy, annual equivalent =	#DIV/0!
Energy Cosumption: Inhabitation =	#DIV/0!
Embodied CO2, annual equivalent =	#DIV/0!
CO2 Emission: Inhabitation =	#DIV/0!
Gross Energy Consumption (kWh) =	#DIV/0!
Net Energy Consumption (kWh) =	#DIV/0!

Refer to Table Z for energy costs and standing charges

Primary Space Heating fuel cost (£.kWh-1):	0.0594	#DIV/0!
Secondary Space Heating fuel cost (£.kWh-1):		#DIV/0!
Water Heating fuel cost (£.kWh-1):	0.0594	#DIV/0!
Pumps and fans fuel cost (£.kWh-1):	0.0594	0.0

Lights and Appliances fuel cost (£.kWh-1):	0.0594
Cooking fuel cost (£.kWh-1):	0.01295
Gas Standing Charge, if applicable (£.annum-1):	25.5675
Electricity Standing Charge, if applicable (£.annum-1):	34.2969

	0.0
	0.0
	12483.5
	16745.7
Total Energy Cost (£)=	#DIV/0!
Lifecycle Cost per Unit Floor Area (£.m-2) =	#DIV/0!
Lifecycle Cost per Unit Floor Area per Annum(£.m-2) =	#DIV/0!

Life Cycle Water Consumption and Cost

Potable water consumption (litres) =	#DIV/0!
Total water consumption (litres) =	#DIV/0!

Refer to Table AA for water costs and standing charges

Potable water costs (£.l-1):	0.000704
Sewerage water costs (£.l-1):	0.000510
Potable Standing Charge, if applicable (£.annum-1):	25.70
Sewerage Standing Charge, if applicable (£.annum-1):	11.31
Highway & Drain Standing Charge, if applicable (£.annum-1):	68.89

	#DIV/0!
	#DIV/0!
	12547.06
	5521.10
	33634.71
Total Water Cost (£)=	#DIV/0!
Lifecycle Cost per Inhabitant (£.m-2) =	#DIV/0!
Lifecycle Cost per Inhabitant per Annum (£.m-2) =	#DIV/0!

Table A

Comparable Benchmarks of Air Tightness (ac.h-1 @ 50 Pa)	
Precedent Values	Air Tightness
Typical current practice for volume housebuilder in United Kingdom	10 to 15
Proposed value for 2001 in revision to Part L of the Building Regulations	8.2
Potential proposed value for 2002 in revision to Part L of the Building Regulations	4.1
Potential proposed value for 2007 in revision to Part L of the Building Regulations	2.5
Equivalent Swedishish Building Regulation Standard from SBN-80	2.4

Low Energy Dwelling Precedents and Construction Methods	Air Tightness
Lower Watts, Oxfordshire. Concrete beam + block gnd floor; masonry cavity walls; timber upper floor and roof; polyethylene vapour barrier throughout roof only.	3.6
Winslow, Milton Keynes. Concrete beam + block gnd floor; double layer timber frame walls with brick cladding; timber roof.	1.9
Lifestyle 2000, Milton Keynes. Suspended timber gnd floor; brick clad cavity timber frame walls; timber roof; mechanical ventilation	1.7
Two Mile Ash, Milton Keynes. Concrete slab gnd floor; timber frame with brick cladding; timber roof; joints in timber frame in-situ polyurethane foam sealed.	1.5
Duncan House, Canada. Suspended timber gnd and upper floors; double layer timber frame walls; timber roof; polyethlene vapour barrier throughout.	0.5
Solar House, Friberg, Gmy. Suspended concrete gnd floor; 300mm calcium silicate block walls; concrete slab flat roof.	0.3
House, Southwell, UK. Precast concrete floors; dense block and brick walls; timber roof; wet plastered throughout; air barrier across roof.	0.2
Passive Haus, Gmy. Insitu concrete floors; 175mm calcium silicate block walls externally rendered; timber roof; polyethylene vapour barrier throughout.	0.2
House B, Hjortkaer, Denmark. Suspended timber gnd floor; brick clad timber frame walls; timber roof; polyethylene vapour barrier throughout.	0.2
Zero Energy House, St Gallen, Switzerland. Double layer timber frame walls, timber-clad; timber floor; with carefully detailed air barrier throughout.	0.17
Urban House in Paradise ideal benchmark	0.17

Table B

	Surface Resistances				
	Building Element	Exposure	Heat flow	High Emissivity	Low Emmissivity
Rsi	Wall	-	Horizontal	0.12	0.3
	Ceiling, roof, floor	-	Upward	0.10	0.22
		-	Downward	0.14	0.55
Rcav	5 mm thick	-	Horizontal	0.10	0.18
		-	Upward	0.10	0.18
		-	Downward	0.10	0.18
	>= 25 mm thick	-	Horizontal	0.18	0.35
		-	Upward	0.17	0.35
		-	Downward	0.22	1.06
Rso	Wall	Sheltered	-	0.08	0.11
		Normal	-	0.06	0.07
		Exposed	-	0.03	0.03
	Roof	Sheltered	-	0.07	0.09
		Normal	-	0.04	0.05
		Exposed	-	0.02	0.02

Table C

Material Conductivity, Density and Embodied Enegy			
Material	Conductivity - λ (W.m-1.K-1)	Density (kg.m-3)	Em Energy (kWh.kg-1)
Aluminium	238	2,700	56.0
Brick	1.21	1,750	1.2
Cement	1.44	1,300	2.2
Cellulose fibre insulation	0.035	24 roof, 40 walls	0.46
Dense concrete	1.44	2,600	0.2
Felt	0.2	960	4.2
Glass	1.05	2,500	6.0
Glass fibre	0.04	12	8.3
Granite	2.5	2,600	-
Gravel	-	-	0.01
Lightweight concrete block	0.19	,200	0.5
Mineral wool	0.038	50	3.9
Plaster	0.46	1,300	1.0
Polystyrene	0.034	30	14.7
Polyvinyl chloride	0.17	1,050	14.7
Render	0.53	1,300	0.5
Roofing tiles: clay	0.85	1,900	0.1
Roofing tiles: concrete	1.1	2,100	0.1
Sand	-		0.01
Steel	397	7,900	10.0
Timber	0.14	700	0.1
Urethane foam	0.023	30	23.6

Table D

β in Terms of Length / Breadth Ratio	
length / breadth	β
1	1.6
2	1.3
3	1.2
4	1.13
6	1.1
∞	1

Table E

Insulation thickness, (mm)	Cylinder		Storage Combination Boiler		Thermal Store and CPSU	
Hot Water Storage Loss Factor (GJ.a-1.litre)	Factory insulated	Loose jacket	Primary store	Secondary store	Hot water only store	Integrated store or CPSU
None	0.0945	0.0945	0.1417	0.0945	0.1417	-
12.5	0.0315	0.0725	0.0473	0.0315	0.0473	-
25	0.0158	0.0504	0.0236	0.0158	0.0236	-
38	0.0104	0.0332	0.0156	0.0104	0.0156	0.029
50	0.0079	0.0252	0.0118	0.0079	0.0118	0.0221
80	0.0049	0.0158	0.0074	0.0049	0.0074	0.0138
100	0.0039	0.0126	0.0059	0.0039	0.0059	0.011
150	0.0026	0.0084	0.0039	0.0026	0.0039	0.0074

Table F

Primary Circuit Losses (GJ.a-1)	
Electric immersion heater	0
Boiler with uninsulated primary pipework and no cylinderstat	4.4
Boiler with insulated primary pipework and no cylinderstat	2.2
Boiler with uninsulated primary pipework and withcylinderstat	2.2
Boiler with insulated primary pipework and with cylinderstat	1.3
CPSU, or boiler and thermal store within a single casing, connected by less than 1.5m of lagged primary pipework, otherwise use appropriate value	0
Community heating	1.3

Table G1

Heating System Seasonal Efficiency (Space and Water)			
Type of System	Efficiency (%)	Heating Type	Responsiveness
Central Heating Systems with Radiators			
Gas and Oil Boilers			
For efficiency, use manufacturers's SEDBUK value, or value from Table G2. If boiler is supplying underfloor heating as opposed to radiators, apply efficiency adjustment in Table G3 if relevant. Obtain heating type and responsiveness from Table G4.			
Solid Fuel Boilers			
Manual feed (in heated space)	60	2	0.75
Manual feed (in unheated space)	55	2	0.75
Autofeed (in heated space)	65	2	0.75
Autofeed (in unheated space)	60	2	0.75
Open fire with back boiler to radiators	55	3	0.50
Closed fire with back boiler to radiators	65	3	0.50
Electric Boilers			
Dry-core boiler in heated space	100	2	0.75
Dry-core boiler in unheated space	85	2	0.75
Water storage boiler in heated space	100	2	0.75
Water storage boiler in unheated space	85	2	0.75
Direct acting air-to-water heat pump	250	1	1.0
Community Heating Schemes	100	1	1.0
Refer to Table G5 for control options. Check Table G4 for efficiency and adjustment due to poor controls			
Storage Radiator Systems			
Off peak tariff:			
Old (large volume) storage heaters	100	5	0.0
Modern (slimline) storage heaters	100	4	0.25
Convector storage heaters	100	4	0.25
Fan storage heaters	100	3	0.5
Electric underfloor heating	100	5	0.0
Modern (slimline) storage heaters (+ CELECT controls)	100	3	0.5
Convector storage heaters (+ CELECT controls)	100	3	0.5
Fan storage heaters (+ CELECT controls)	100	2	0.75
24-hour heating tariff			
Modern (slimline) storage heaters	100	3	0.5
Convector storage heaters	100	3	0.5
Fan storage heaters	100	3	0.5
Modern (slimline) storage heaters (+ CELECT controls)	100	2	0.75
Convector storage heaters (+ CELECT controls)	100	2	0.75
Fan storage heaters (+ CELECT controls)	100	2	0.75

Type of System	Efficiency (%)	Heating Type	Responsiveness
Warm-Air Systems			
Gas-fired warm-air with fan assisted flue			
Ducted, with gas-air modulation	80	1	1.0
Room heater, with in-floor ducts	77	1	1.0
Gas-fired warm-air with balanced or open flue			
Ducted (on/off control)	70	1	1.0
Ducted (modulating control)	72	1	1.0
Stud ducted	70	1	1.0
Ducted with flue heat recovery	85	1	1.0
Stud ducted with flue heat recovery	82	1	1.0
Condensing	94	1	1.0
Oil-fired warm-air			
Ducted output (on/off control)	70	1	1.0
Ducted output (modulating control)	72	1	1.0
Stud ducted system	70	1	1.0
Electric warm-air			
Electricaire system	100	2	0.75
Direct-acting air-to-air heat pump	250	1	1.0
Room Heater Systems			
Gas			
Old-style gas fire (open front)	50	1	1.0
Modern gas fire with open flue	60	1	1.0
Modern gas fire with balanced flue	70	1	1.0
Modern gas fire with back boiler (no radiators)	65	1	1.0
Condensing gas fire (fan-assisted flue)	85	1	1.0
Gas fire or room heater with fan-assisted flue	79	1	1.0
Coal-effect heater (open to chimney)	25	1	1.0
Coal-effect heater (flued)	60	1	1.0
Solid fuel			
Open fire in grate	32	3	0.5
Open fire in grate, with throat restrictor	42	3	0.5
Open fire with back boiler (no radiators)	55	3	0.5
Closed room heater	60	3	0.5
Closed room heater with back boiler (no radiators)	65	3	0.5
Electric (direct-acting)			
Panel, convector or radiant heaters	100	1	1.0
Portable electric heaters	100	1	1.0
Other Space and Water Heating Systems			
Electric ceiling heating	100	2	0.75
Other Water Only Heating Systems			
Independent electric water heating system	100		
Single-point gas water heater	70		
Multi-point gas water heater	65		
From a heat exchanger built into a gas warm-air system	65		
Type of System	Efficiency (%)	Heating Type	Responsiveness

Table G2 & 3

Seasonal Efficiency for Gas and Oil Boilers	
Boiler type	Efficiency (%)
Gas Boilers (inc LPG) 1998 or later	
Non-condensing (inc combies) with auto ignition	73
Condensing (inc combies) with auto ignition	83
Non-condensing (inc combies) with pilot light	69
Condensing (inc combies) with pilot light	79
Room heater + back boiler	65
Gas Boilers (inc LPG) pre-1998, fan-assit'd flue	
Low thermal capacity	72
High or unknown thermal capacity	68
Combi	70
Condensing combi	84
Condensing	85
Gas Boilers (inc LPG) pre-98, balanced/open flue	
Wall-mounted	65
Combi	65
Room heater + back boiler	65
Combined Primary Storage Units	
With permanent pilot light	70
With automatic ignition	74
Oil Boilers	
Standard oil boiler, 1998 or later	79
Condensing	83
Combi, pre-1998	70
Combi, 1998 or later	76
Condensing combi	80

Seasonal Efficiency Adjustment for Thermal Stores and Underfloor Heating from Gas or Oil Boilers		
Boiler / Thermal Storeage Type	Efficiency Adjustment	
	Space heating	Water Heating
Non-condensing gas boiler, efficiency 72 or 68%		
Integrated thermal store	add 2	add 2
Hot water only thermal store	0	add2
Underfloor heating	add 2	0
Condensing gas boiler, efficiency 85 %		
Integrated thermal store	subtract 2	add 2
Hot water only thermal store	0	add 2
Underfloor heating	add 2	0
Non-condensing gas boiler, efficiency 65%		
Integrated thermal store	add 3	add 3
Hot water only thermal store	0	add 3
Underfloor heating	add 2	0
Non-condensing oil boiler, efficiency 83%		
Integrated thermal store	subtract 2	add 2
Hot water only thermal store	0	add 2
Underfloor heating	add 2	0

Table G4

Heating Types and responsiveness for Gas and Oil Boilers		
Heat Emitter	Heating Type	Responsiveness (R)
Radiators	1	1.0
Underfloor heating, pipes in concrete floor	4	0.25
Underfloor heating, pipes in chipboard floor panels	3	0.5

Table G5

Heating System Controls			
Type of Control	Control	Efficiency Adustment (%)	Temp Adustment (oC)
Boiler Systems with Radiators			
No thermostatic control of room temperature	1	-5	0.3
Programmer + roomstat	1	0	0
Programmer + roomstat (no boiler interlock)	1	-5	0
Programmer + roomstat + TRVs	2	0	0
Programmer + roomstat + TRVs (no boiler interlock)	2	-5	0
TRVs + programmer + bypass	2	-5	0
TRVs + programmer + flow switch	2	0	0
TRVs + programmer + boiler energy manager	2	0	0
Full zone control	3	0	0
Full zone control (no boiler interlock)	3	-5	0
Intelligent heating controller	1	0	-0.5
Intelligent heating controller (no boiler interlock)	1	-5	-0.5
Intelligent heating controller + TRVs	2	0	-0.5
Intelligent heating controller + TRVs (no boiler interlock)	2	-5	-0.5
Delayed start thermostat + programmer	1	0	-0.2
Delayed start thermostat + programmer (no boiler interlock)	1	-5	-0.2
Delayed start thermostat + programmer + TRVs	2	0	-0.2
Delayed start thermostat + programmer + TRVs (no boiler interlock)	2	-5	-0.2
Community Heating Systems			
Flat rate charging, no thermostatic control of room temperature	1	-10	0.3
Flat rate charging, programmer and roomstat	1	-5	0
Flat rate charging, programmer and TRVs	2	0	0
Charging system linked to use of community heating, programmer and TRVs	3	0	0
Storage Radiator Systems			
Manual charge control	3	0	0.3
Automatic charge control	3	0	0
CELECT-type controls	3	0	0
Warm-Air Systems			
No thermostatic control of room temperature	1	0	0.3
Roomstat only	1	0	0
Programmer + roomstat	1	0	0
Zone control	3	0	0
Room Heater Systems			
No thermostatic control	2	0	0.3
Appliance stat	3	0	0
Appliance stat + programmer	3	0	0
Programmer + roomstat	3	0	0
Roomstat only	3	0	0
Other Systems			
No thermostatic control of room temperature	1	0	0.3
Roomstat only	1	0	0
Programmer + roomstat	1	0	0
Programmer + zone control	3	0	0

Table H

Lighting, Appliances, Cooking and Metabolic Gains (W)				
Floor area (m2) =	Gains (W)			
0	Typical energy consumption	Efficient Scenario 1	Efficient Scenario 2	Efficient Scenario 3
30	230	207	161	69
40	282	254	197	85
50	332	299	232	100
60	382	344	267	115
70	431	388	302	129
80	480	432	336	144
90	528	475	370	158
100	576	518	403	173
110	623	561	436	187
120	669	602	468	201
130	715	644	501	215
140	760	684	532	228
150	805	725	564	242
160	849	764	594	255
170	893	804	625	268
180	935	842	655	281
190	978	880	685	293
200	1020	918	714	306
210	1061	955	743	318
220	1102	992	771	331
230	1142	1028	799	343
240	1181	1063	827	354
250	1220	1098	854	366
260	1259	1133	881	378
270	1297	1167	908	389
280	1334	1201	934	400
290	1349	1214	944	405
300	1359	1223	951	408

Note: for the following equipment, add the following gains in addition to the above:

Central heating pump	10 W
Warm-air heating system fans	10 W
Mechanical ventilation sytem, (discount fans above if mech vent system)	25 W

Table I

Solar Flux Through Glazing (W.m-2)						
Glazing type	Horizontal	Vertical				
		North	NE/NW	E/W	SE/SW	South
Single glazed	34	13	15	22	29	32
Double glazed	30	11	13	19	26	28
Double - Low E, soft	22	9	10	15	19	22
Double - Low E, hard	28	11	13	18	25	27
Triple Glazed	26	10	12	17	23	25

Table J

Solar Access factor		
Overshading	% Sky Blocked	Solar access factor
Heavy	>80	0.4
More than average	60-80	0.7
Average or unknown	20-60	1
Very little	<60	1.3

Table K

Utilisation Factor as function of Gains to Loss Ratio (GLR)					
GLR, which = #DIV/0!	Utilisation factor	GLR, which = #DIV/0!	Utilisation factor	GLR, which = #DIV/0!	Utilisation factor
1	1.00	11	0.81	21	0.58
2	1.00	23	0.78	22	0.56
3	1.00	13	0.75	23	0.54
4	0.99	14	0.72	24	0.53
5	0.97	15	0.70	25	0.51
6	0.95	16	0.68	30	0.45
7	0.92	17	0.65	35	0.40
8	0.89	18	0.63	40	0.36
9	0.86	19	0.61	45	0.33
10	0.83	20	0.59	50	0.30

Table L

Mean Internal Temperature of Living Area (oC)					
HLP, which = #DIV/0!	Heating type (see Table F1 or F5)				
	1	2	3	4	5
<=1.0	18.88	19.32	19.76	20.21	20.66
1.5	18.88	19.31	19.76	20.20	20.64
2.0	18.85	19.30	19.75	20.19	20.63
2.5	18.81	19.26	19.71	20.71	20.61
3.0	18.74	19.19	19.66	20.13	20.59
3.5	18.62	19.10	19.59	20.08	20.57
4.0	18.48	18.99	19.51	20.03	20.54
4.5	18.33	18.86	19.42	19.97	20.51
5.0	18.16	18.73	19.32	19.90	20.48
5.5	17.98	18.59	19.21	19.82	20.45
>=6.0	17.78	18.44	19.08	19.73	20.40

Table M

Difference in Temperature Between Zones (oC)			
HLP, which = #DIV/0!	Heating type (see Table G1 or G5)		
	1	2	3
<=1.0	0.40	1.41	1.75
1.5	0.60	1.49	1.92
2.0	0.79	1.57	2.08
2.5	0.97	1.65	2.22
30.0	1.15	1.72	2.35
3.5	1.32	1.79	2.48
4.0	1.48	1.85	2.61
4.5	1.63	1.90	2.72
5.0	1.76	1.94	2.83
5.5	1.89	1.97	2.92
>=6.0	2.00	2.00	3.00

Table N

Degree Days as a Function of Base Temperature					
Base temp, which = #DIV/0!	Degree days	Base temp, which = #DIV/0!	Degree days	Base temp, which = #DIV/0!	Degree days
1.0	0	8.0	620	15.0	2015
1.5	30	8.5	695	15.5	2130
2.0	60	9.0	775	16.0	2250
2.5	95	9.5	860	16.5	2370
3.0	125	10.0	950	17.0	2490
3.5	150	10.5	1045	17.5	2610
4.0	185	11.0	1140	18.0	2730
4.5	220	11.5	1240	18.5	2850
5.0	265	12.0	1345	19.0	2970
5.5	310	12.5	1450	19.5	3090
6.0	360	13.0	1560	20.0	3210
6.5	420	13.5	1670	20.5	3330
7.0	480	14.0	1780	-	-
7.5	550	14.5	1900	-	-

Table O

Water Consumption (l.d-1)		
	Total consumption	Hot water consumption
Typical consumption (litres.person-1.day-1)	160	66

For total consumption on basis of functions, add appropriate values below or use actual consumption values

Consumption on basis of function (litres.person-1.day-1)		
Function or Appliance/fitting	Total consumption	Hot water consumption
Drinking and cooking	6.5	0
Standard WC (6 litre flush)	56	0
Low flush WC (3 litre flush)	28	0
Composting WCs	0	0
Personal Hygiene (bath and shower)	26	18
Personal Hygiene (shower only)	21	18
Personal Hygiene (low flow shower only)	16	14
Personal Hygiene (hand and face washing)	5	4.5
Washing machine - standard	16	14
Washing machine - low water consumption	12	10
Washing machine (zero hot water)	16 or 12	0
Dishwashing by hand	10	9
Dishwasher - standard (x litre consumption)	7	0
Dishwasher - low consumption (y litre consumption)	5	0
Outdoor use	10	0

Table O1

Hot Water Energy Requirements and Distribution Losses (GJ.a-1)					
Floor Area, which = 0.0	Hot water usage	Distribution losses	Floor Area, which = 0.0	Hot water usage	Distribution losses
30	4.13	0.73	170	10.40	1.84
40	4.66	0.82	180	10.75	1.90
50	5.16	0.91	190	11.10	1.96
60	5.68	1.00	200	11.43	2.02
70	6.17	1.09	210	11.74	2.07
80	6.65	1.17	220	12.06	2.13
90	7.11	1.26	230	12.34	2.18
100	7.57	1.34	240	12.62	2.23
110	8.01	1.41	250	12.89	2.27
120	8.44	1.49	260	13.15	2.32
130	8.86	1.56	270	13.39	2.36
140	9.26	1.63	280	13.62	2.40
150	9.65	1.70	290	13.84	2.44
160	10.03	1.77	300	14.04	2.48

Table O2

Distribution Loss Factor for Group and Community Heating	
System Type	Factor
Mains piping system installed in 1990 or before, not pre-insulated, medium or high temperature distribution (120-140 oC), full flow system	1.20
Pre-insulated mains piping system installed in 1990 or before, low temperature distribution (100 oC or below), full flow system	1.10
Modern higher temperature system (up to 120 oC), using pre-insulated mains installed in 1991 or later, variable flow system	1.10
Modern pre-insulated piping system operating at 100 oC or below, full control system installed in 1991 or later, variable flow system	1.05

Table P

Average Rainfall (mm.a-1)	
Station	Anuual total (mm)
Belfast	912
Birmingham	679
Cardiff	947
Edinburgh	677
Glasgow	982
London	617
Manchester	819
Plymouth	990

Table Q

Fraction of Heat Supplied by Secondary Heating System		
Main heating system	Secondary system	Fraction
Central, boilers, rads; central warm air; other gas-fired system	Gas fires	0.15
	Coal fires	0.10
	Electric heater	0.05
Gas room heaters	Gas fires	0.30
	Coal fires	0.15
	Electric heater	0.10
Coal room heaters; electric room heaters	Gas fires	0.20
	Coal fires	0.20
	Electric heater	0.20
Electric storage, not fan assisted; other electric systems	Gas fires	0.15
	Coal fires	0.10
	Electric heater	0.10
Electric pump systems with heat storage; fan-assisted storage h'ters	Gas fires	0.15
	Coal fires	0.10
	Electric heater	0.05

Table R

Energy Consumption by Appliances on Basis of Individual Appliance Consumption (kWh.a-1)			
Appliance	Examples of Appliance Consumption		
	Low Efficiency	Medium Efficiency	High Efficiency
Fridge	595	475	240
Washing Machine	190	156	142
Dishwasher	256	193	133
Tumble Dryer	1140	523	475
Kettle	562	218	-
Toaster	-	17	-
Coffee Maker	-	41	-
Deep Fat Fryer	-	36	-
Television	-	164	-
Video	-	52	-
Vacuum Cleaner	-	96	-
Personal Computer	-	175	-
Clocks	-	96	-
Cooker	656	410	300
Microwave Oven	-	46	-

Table S

Energy Consumption by Lighting and Appliances on Basis of Floor Area				
Floor Area, which = 0	Typical consumption	Efficient Scenario 1	Efficient Scenario 2	Efficient Scenario 3
30	694	625	486	208
40	944	850	661	283
50	1167	1050	817	350
60	1417	1275	992	425
70	1639	1475	1147	492
80	1861	1675	1303	558
90	2111	1900	1478	633
100	2333	2100	1633	700
110	2583	2325	1808	775
120	2806	2525	1964	842
130	3028	2725	2120	908
140	3278	2950	2295	983
150	3500	3150	2450	1050
160	3750	3375	2625	1125
170	3972	3575	2780	1192
180	4194	3775	2936	1258
190	4444	4000	3111	1333
200	4667	4200	3267	1400
210	4917	4425	3442	1475
220	5139	4625	3597	1542
230	5361	4825	3753	1608
240	5611	5050	3928	1683

Table Y

HCFC Emissions from Insulation	
Insulation type	Emission (kgHCFC.m-3)
Urethane foam	0.12

Table Z

Energy Costs (£.kWh-1)	
Bulk LPG	0.02610
Gas	0.01295
Heating Oil	0.01433
House Coal	0.01530
Mains Electricity	0.05940
Smokeless Fuel	0.02560
Wood	0.01526

Standing Charge Energy Costs (£.a-1)	
Bulk LPG	54.00000
Gas	25.5675
Mains Electricity	34.2969

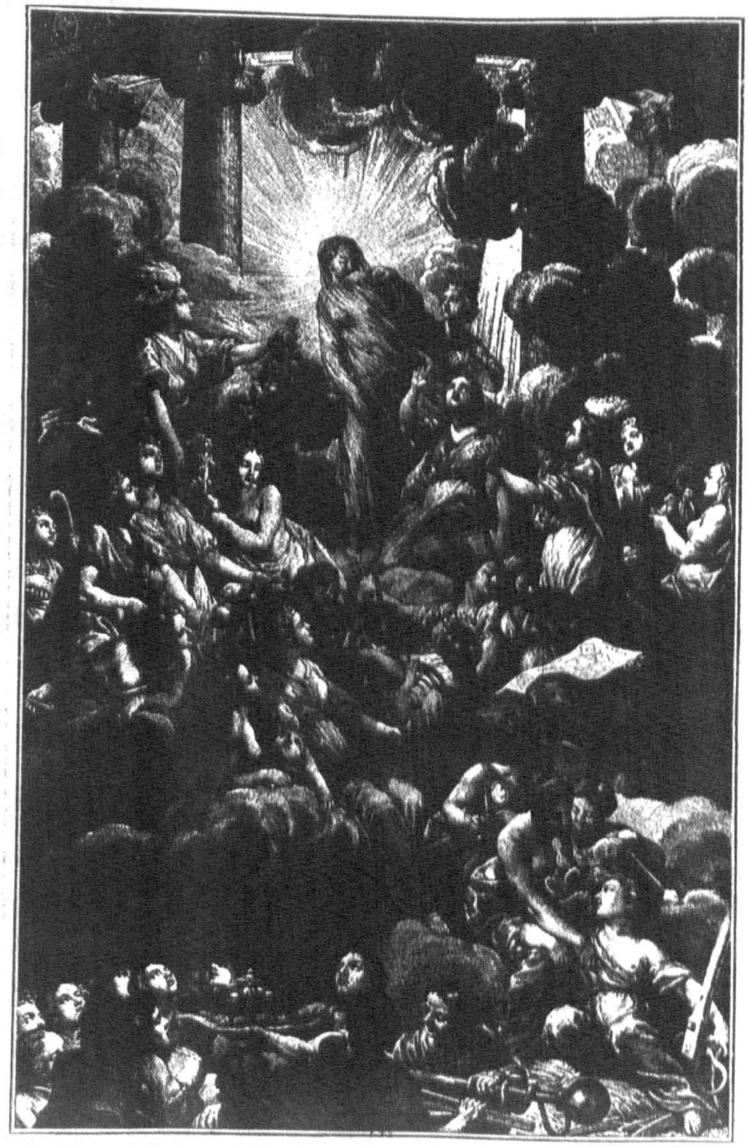
Table AA

Water Costs (£.l-1)	
Potable Mains	0.000704
Sewerage	0.000510

Standing Charge Water Costs (£.a-1)	
Potable Mains	25.70
Sewerage	11.31
Highway & Drainage	68.89

The criteria that define the 'urban house in paradise' have been identified and quantitative benchmarks for those criteria established. Having determined the inadequacies of existing environmental assessment methods a number of shortcomings were highlighted; these included both a lack of hierarchy and recognition of interrelated linkages between criteria, a lack of consideration for the longevity of the building, and frequent anthropocentric bias. A tool was then devised for assessing dwellings against the criteria of the 'urban house in paradise' that attempted to overcome these shortcomings. To focus the scope of the research the assessment measures the eleven criteria that contribute most to increasing the ecological sustainability of the dwelling, as identified during the prioritising of the criteria. The next stage of the research was to validate this work. This would establish how robust and accurate the criteria, benchmarks and assessment tool are, through literature review, the final drawn studies and critiques by specialists.

Chapter 11



Validation and Testing

11.0 Validation and Testing

With the benchmarks for the criteria that define the 'urban house in paradise' established, and the methodology of assessing a design for a dwelling against those benchmarks determined, the next stage of the study was to validate both the benchmarks and the assessment tool. This will ratify how robust and accurate these outcomes of the research are.

11.1 The Validation Methodology

The validation of the tool was achieved firstly by assessing a three bedroom semi-detached dwelling to determine how closely it predicts the values derived through literature review, secondly by assessing the final drawn studies, and thirdly through specialist interviews. Validating the research from three independent directions increased the confidence in its robustness.

The validation of the assessment tool and its benchmarks was conducted in three independent ways. The first method was to conduct an assessment of a 'typical' three bedroom semi-detached dwelling, in order to determine how closely the tool predicted its performance against the benchmarks proposed by the thesis from literature review, validating therefore both the tool and the benchmarks. Secondly an assessment was made through the final drawn studies. These provide a design project through which to test that the proposed benchmarks are achievable, and not mutually exclusive, and to use as a project that was assessed using the tool. Each of the benchmarks was also assessed by manual calculation, to ensure that the values produced by the tool were accurate. The third method of validation was through a critical appraisal by specialist interviews. These were structured through a questionnaire, to provide a consistent critical format to the process. The tool and benchmarks have been analysed through using drawn studies Six to Eight to test its application on an evolving design project, as an architect would use the tool within a practice environment. Specialist interviews with an architect and a building services engineer were undertaken to ensure that the algorithms and equations used within the assessment methodology are correct and robust. Therefore a triangulated approach was adopted in the validation of the 'urban house in paradise' assessment tool, through the drawn studies, the specialist interviews and the literature review; this increased confidence in its robustness.

11.2 Three Bedroom Semi-detached Dwelling

The tool was validated using an assessment of a typical three bedroom semi-detached dwelling to determine the consistency between the predicted benchmarks and the values derived from the literature review. On a comparable basis, the two methods produced values within 5 percent of each other.

The tool was used to assess a three bedroom semi-detached dwelling built to current Building Regulation standards.[1] The objective of this analysis was to determine the correlation between the values for the benchmarks determined by the tool and the values determined by the literature review for a typical dwelling built to current regulatory standards.[2] This will validate both the tool and, provided that the other validation processes conclude the tool is accurate, the proposed benchmarks. The outcome can be seen in the table below.

Criteria	Benchmarks		
	Literature	Assessed	Variation (%)
Energy Consumption: Inhabitation	194	199.6	+ 2.8
Energy Generation: Inhabitation	0	0	0
Q of I E: Ventilation and Air Tightness	13	13	0
Ecological Weight: Embodied Energy	1,000	924.4	- 8.1
CO_2 Emissions: Inhabitation	50.4	52.8	+4.5
Design Life Span	60	60	0
Pollution: Energy Consumption Inhabitation	2.002	2.102	+ 4.8
Thermal Performance: roof	0.25	0.25	0
Thermal Performance: walls	0.45	0.43	- 4.4
Thermal Performance: ground floor	0.45	0.43	- 4.4
Thermal Performance: doors	3.3	3.3	0
Thermal Performance: windows	3.3	3.3	0
Ecological Weight: Embodied CO_2 Emissions	360	323.5	- 10.3
Other Greenhouse Gas Emissions	0	0	0
Water Consumption: Inhabitation	160	160	0

Table 11: Benchmark performance of a three bedroom semi-detached dwelling determined by literature review and the 'urban house in paradise' assessment tool

There is a relatively high degree of consistency between the two sets of benchmarks, which varies between 10.3 percent under and 4.8 percent over the benchmark value determined

[1] A copy of the assessment is located at the end of this chapter.
[2] Refer to Chapter 4.0, Benchmarking the 'Urban House in Paradise', and Annexe 3.0, Benchmark Analysis of the Criteria, in volume 3.

by literature review. A reason for the 8.1 percent discrepancy between the Ecological Weight: Embodied Energy values is that the tool assessed the energy embodied in the envelope, floors and foundations of the dwelling, and not the energy embodied in the services, fixtures and fittings, such as the pipework and radiators of the heating system. This would also account for the discrepancy in the Ecological Weight: Embodied CO_2 Emissions values. Although aimed to assess the energy embodied in the envelope of the dwelling at present, the methodology of the embodied energy calculation can be expanded to account for such factors. If, therefore, the values of embodied energy and CO_2 are discounted for the moment, the tool predicted the benchmarks to within 5 percent of the values derived from literature review. This would suggest that confidence can be taken in their values, and that the tool provides an adequate method of assessing those benchmarks.

11.3 The Drawn Studies

Drawn Studies Six, Seven and Eight were designed to achieve the collective benchmarks of the 'urban house in paradise'. This was to ensure that all of the benchmarks can be achieved collectively, and that none are mutually exclusive.

Following the development of the benchmarks and assessment tool, the final drawn studies were undertaken as part of the validation methodology. These studied the masterplan for a site in the Ancoats area of Manchester city centre, the design for a dwelling within that masterplan, and the proposed technology through which that dwelling would be constructed. The ambition was to design an urban plan and dwelling that would, in combination, achieve the collective benchmarks of the 'urban house in paradise', and ensure that none are mutually exclusive; the studies themselves are located within volume two, accompanied by a description of the project and analysis of their performance against the benchmarks.

The performance benchmarks of the drawn studies can be seen in comparison to those of the 'urban house in paradise' in the table overleaf. The Water Consumption: Inhabitation benchmark had a detrimental impact on achieving other benchmarks, such as Ecological Weight: Embodied Energy and CO_2 and Lifecycle Cost; essentially all of the other benchmarks were met. The text that follows analyses where there are significant differences between the two and other pertinent issues in achieving the benchmarks of the 'urban house in paradise'.

Criteria		Benchmarks	
		Drawn Studies 6, 7 and 8	urban house in paradise'
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		13.8 gross, -1.36 net	≤10.4
CO2 emissions: On Site Construction Processes: kgCO2.m-2		16.1 with basement, 13.5 without	≤27
Carbon intensity: kg.kWh-1		0.31 gross , 0 net	≤0.24
Construction period: weeks per dwelling		6	3
Contextual significance of site: Qualitative		Yes	Yes
Deconstruction and demolition: Recycling materials: Percent		85	≥85
Design life span: Years		120	120
Density:	quantitative: p.ha-1	386	≥370
	qualitative	Yes	Yes and Yes
Diveristy: programmes.ha-1		56	50
Domestic waste:	refuse: kg.p-1.wk-1	2.4	≤2.4
	recycled: kg.p-1.wk-1	7.2	≥7.2
Ecological significance of the site: Percent and qualitative		100, Yes and Yes	100, Yes and Yes
Ecological weight: embodied energy: kWh.m-2		306.0 with basement, 249.8 without	≤250
Ecological weight: CO2 emissions: kgCO2.m-2		107.1 with basement, 87.4 without	≤90
Energy consumption: construction: kWh.m-2		46.0 with basement, 37.5 without	≤75
Energy consumption: inhabitation: kWh.m-2.a-1		24.26	≤25
Energy generation: kWh.m-2.a-1		25.0	≥25, or ≥ c'smpt'n
Green space: Percent		22	20
Lifecycle cost:	Construction: £.m-2.a-1	11.56	≤4.44
	Energy: £.m-2.a-1	7.36	≤7.96
	Water: £.p-1.a-1	124.0	≤97.85
Nitrogen oxide emissions: mg.kWh-1		0.0	≤60
Other ecological impacts of materials: Qualitative, g.kWh-1		A	A, ≤6.596
Other greenhouse gas emissions: g.kg-1		0	0, 0
Pollution: energy consumption inhabitation: g.kWh-1		5.945 gross , -0.748 net	≤1.004
Procurement strategy: Qualitative		Performance spec	Performance spec
Quality of internal environment:	indoor pollution: Qualitative	Yes	Yes
	daylight: living, kitchen, beds: Percent	3.5, 3.5, 4.9	≥ 5, 5, 3.5
	ventilation: ac.h-1	0.45	0.45
	airtightness: ac.h-1 at 50 Pa	0.17	≤0.17
Recycling construction waste: Percent		Not Assessed	≥2.5
Adaptability: Internal loadbearing walls: Internal walls		0	0
Space standards: Area	1 person: m2.p-1	Not Applicable	≥32
	2 persons: m2.p-1	Not Applicable	≥27
	3 persons: m2.p-1	Not Applicable	≥22
	4 persons: m2.p-1	Not Applicable	≥19.7
	5 persons: m2.p-1	21.6	≥19.7
	6 persons: m2.p-1	21.1	≥20.4
	7 persons: m2.p-1	Not Applicable	≥21
	8 persons: m2.p-1	Not Applicable	≥21.7
	9 persons: m2.p-1	Not Applicable	≥21.9
	10 persons: m2.p-1	Not Applicable	≥20.9
Space standards: Volume	1 person: m3.p-1	Not Applicable	≥96
	2 persons: m3.p-1	Not Applicable	≥81
	3 persons: m3.p-1	Not Applicable	≥66
	4 persons: m3.p-1	Not Applicable	≥59.1
	5 persons: m3.p-1	64.8	≥59.1
	6 persons: m3.p-1	70.6	≥61.2
	7 persons: m3.p-1	Not Applicable	≥63.0
	8 persons: m3.p-1	Not Applicable	≥65.1
	9 persons: m3.p-1	Not Applicable	≥65.7
	10 persons: m3.p-1	Not Applicable	≥62.7
Thermal Performance:	Roof: W.m-2.K-1	0.08	≤0.08
	Exposed walls: W.m-2.K-1	0.12	≤0.12
	Ground and exposed floors: W.m-2.K-1	0.10	≤0.13
	Windows and rooflights: W.m-2.K-1	0.80	≤0.80
	Opaque outer doors: W.m-2.K-1	0.55	≤0.55
Use of recycled materials: Percent		100	75
Use of renewable raw materials: Percent		100	100
Utilisation of local resources: km		Not Assessed	45
Water consumption: construction: l.m-2		11.91 with basement, 3.83 without	8.5
Water consumption: inhabitation:	potable: l.p-1.d-1	25.4	6.5
	rain and grey: l.p-1.d-1	12.9	≤35.3
	total: l.p-1.d-1	38.3	≤41.8

Table 12: Collective benchmarks of Drawn Studies 6, 7 and 8 in comparison to those of the 'urban house in paradise'

11.3.1 CO_2 Emissions: Inhabitation

Although the benchmark was met as a net value, the use of electricity to fulfil the majority of energy demands within the dwelling has meant that the gross CO_2 emissions were above the benchmark, despite achieving that of Energy Consumption: Inhabitation. This has also applied to the Pollution Emissions: Energy Consumption Inhabitation and Carbon Intensity benchmarks.

Whilst the net quantity of CO_2 emissions during inhabitation does achieve the benchmark of the 'urban house in paradise' the gross emission does not, being 13.8 as opposed to 10.4 $kgCO_2.m^{-2}.a^{-1}$; this is despite the fact that the Energy Consumption: Inhabitation benchmark is met. Because electricity is used for the significant majority of sources of consumption in the dwelling, which has a much higher emission factor than other fuels,[3] therefore the benchmark was not achieved despite the low energy consumption. Electricity was used because a gas-fired heating system would have been oversized due to the very low heating demand, and electrical mechanical ventilation would have been used anyway. This had a similar impact upon the Carbon Intensity and Pollution Emissions: Energy Consumption Inhabitation benchmarks, which are also achieved in their net but not in their gross values. The only ways in which to achieve the benchmarks for the gross values would be to use a fuel with lower emission factors, such as gas, for more sources of energy consumption, or to further reduce the Energy Consumption: Inhabitation benchmark. Whilst the former would have the additional advantage of further improving the net emissions benchmark, it would mean that the energy generated would be of a different type to that consumed, and therefore the dwelling would be dependent on fossil fuels. However if the storage for excess generation were batteries as opposed to the grid, and the dwelling used electricity throughout, it would be more autonomous and consume no fossil fuels. The disadvantage of the latter approach is that it would not achieve the Pollution Emissions: Energy Consumption Inhabitation benchmark, as this is assessed as a ratio of the fuels used per kilowatt of energy consumed. The gross CO_2 emissions were included in the event that the energy generation of the dwelling did not meet or exceed consumption, which is when emissions would arise as a consequence of the energy consumed by the dwelling, to provide a target for those emissions.

[3] For example the emission factor for electricity is more than double that of natural gas, 0.59 $kgCO_2.kWh^{-1}$ in comparison to 0.19 $kgCO_2.kWh^{-1}$.

11.3.2 Ecological Weight: Embodied Energy

With the basement used for water storage, the drawn study does not achieve the embodied energy benchmark, although it is less than one third that of the typical semi-detached dwelling. If the basement is excluded from the assessment, the benchmark is met. Other construction methods are also inappropriate if the benchmark is to be achieved.

Accommodating the storage volume required for the Mains Water Consumption: Inhabitation benchmark in the drawn study made achieving the Ecological Weight: Embodied Energy benchmark difficult; however this could be because it was stored within a basement. The benchmark value including the basement was 306.0 $kWh.m^{-2}$; however with the basement omitted, the value dropped to 249.8 $kWh.m^{-2}$, which is compliant with the 'urban house in paradise'. As embodied energy is measured per square metre, if the area used for storage were taken into account in the overall area of the dwelling, this would offset the difference; however this might have a detrimental effect on other benchmarks. For example, as the basement is not a part of the inhabited area of the dwelling, it should not be included in the Space Standards benchmarks. Also, it should not be included in the area value used to determine the energy consumption of the dwelling, as it is an unheated space. Including a basement raised the embodied energy value over the benchmark, when it would have been achieved otherwise; this could be reconciled if the Embodied Energy benchmark only applied to the inhabited areas of the dwelling.

The values for embodied energy from using different construction technologies may suggest that setting a benchmark as low as 250 $kWh.m^{-2}$ may dictate that timber frame be used for every dwelling. To demonstrate this, a number of other construction technologies for the walls of the drawn study dwelling were analysed using the assessment tool, to determine the embodied energy; all other variables, such as the floor construction, were kept constant and the basement was excluded. The results are summarised in the table below.

Construction Technology	Embodied Energy (kWh.m-2)
Double skin timber frame	249.8
Brick and concrete blockwork cavity wall	659.3
Double skin concrete blockwork externally rendered	526.3
Single skin concrete wall with rainscreen	542.6

Table 13: Embodied energy for various construction technologies for Drawn Study 7

It is evident from precedents[4] that timber frame dwellings can achieve very high performance standards, whilst being built from a renewable resource and using relatively low levels of embodied energy; this suggests a direction that the benchmark of Ecological Weight: Embodied Energy could be used to instigate. However, it could also be concluded that the benchmark of 250 kWh.m^{-2} impinges upon the creative design of the dwelling, in terms of materiality, which the criteria and benchmarks sought to avoid. The issue of thermal mass also has an impact upon the potential revision of the Ecological Weight: Embodied Energy benchmark, as discussed below.

11.3.3 Energy Consumption: Inhabitation

The Energy Consumption: Inhabitation benchmark was achieved; the tool proved useful in identifying the largest component in that consumption, lights and appliances, and therefore the potential value in demonstrating the significance that lifestyle behaviour can have on the performance of low-energy dwellings.

When the assessment of the Energy Consumption: Inhabitation benchmark for the drawn study by the assessment tool is broken down into its component parts, it can be seen that the energy consumption values for lighting and appliances is the largest component of the total energy consumption, 32 percent as opposed to the next highest, water heating, of 26 percent. Two conclusions can be made from this observation. Firstly, that the lighting and appliances offers the greatest opportunity to further reduce the energy consumption of the dwelling during its life span; secondly, that in being able to respond to scenarios of using more efficient lighting systems and domestic appliances the assessment tool is a significant advance on current energy assessment methods for dwellings.[5]

However, both of these points are governed by the fact that this component may well, to a large extent, be dependent upon the inhabitants of the dwelling, and therefore be beyond the control of the designer. Energy efficient lights can be specified in the first instance, but

[4] There are a number of timber frame ultra-low-energy dwellings, including the Low-Energy House B, in Denmark, the Waterloo Region Green Home in Canada, the Zero-Energy Dwelling in Switzerland, and the Duncan House in Canada. BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, London: HMSO, February 1996.

[5] In response to the latter, *GIR 53* provides data that was used to provide different scenarios of the consumption various degrees of efficiency for lights and appliances, from the typical dwelling, to zero CO_2, zero heating and autonomous standards. These were also used to refine the tables in the tool, if the assessment is to be based on floor area. The values provided in *GIR 53* are for a whole dwelling. These can be converted into percentages of each other, thereby determining the percentage reduction for each of the more efficient scenarios. These reductions can then be applied to the values

this does not ensure that they are not replaced with standard tungsten bulbs. Similarly, one cannot ensure that inhabitants have energy efficient white goods.[6] The impact of lifestyle beyond the scope of the dwelling was discussed in the Introduction, and the significance that the increase in the ecological sustainability of the dwelling should be integral to a wider drive to more sustainable lifestyles was demonstrated. Behavioural lifestyle will also impact upon this component, in terms of inhabitants using lighting and appliances in an efficient manner.

This shows how important education of the inhabitants will become in very low energy dwellings. The tool could have a role to play in this, by demonstrating how much energy and, therefore, money could be saved by inhabitants if they adopt certain lifestyle habits, such as using washing machines on full load and replacing compact fluorescent light fittings. It could be possible that housing providers, both private and public, could also undertake to offer inhabitants energy efficient appliances that meet the different scenarios proposed by the tool, demonstrating the balance between capital cost and potential energy saving. Regulation could also provide a mechanism to increase the efficiency of appliances over time.

11.3.4 Energy Generation: Inhabitation

The benchmark for Energy Generation: Inhabitation is also achieved. However, creating sufficient roof area on the southern elevation for the photovoltaic array could require an asymmetric profile; this might be considered a restrictive influence on the design of the dwelling, as it would affect the architectural form of the envelope.

To achieve a sufficient area of photovoltaic panels may require the use of an asymmetrical roof profile. This raises the issue of the benchmarks influencing design decisions. The specific intention was made that pursuing the benchmarks would not influence or dictate design solutions, potentially creating a monistic approach to design. The benchmarks are not regulatory, and therefore the decision could be taken to choose a solution on its design merits, potentially to the detriment of one or more of the benchmarks. The benchmarks and tool provide measurement and assessment in terms of the most ecologically sustainable resolution (and not the *only* solution) from which decisions can be made on the basis of the considered opinion of the designer.

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in the table derived from BREDEM data which gives the energy consumption as related to the total floor area of a given dwelling to give four different efficiency scenarios for the designer to adopt.

11.3.5 Lifecycle Cost

On the basis of the calculations made and received, the drawn study was not able to achieve the lifecycle cost benchmarks of the 'urban house in paradise'. However, over the life span of the dwelling the cost saving achieved through the reduction in energy and water consumption is 2.5 times more than the difference in capital construction cost between the drawn study and a dwelling constructed using traditional methods to typical performance standards.

On the basis of the cost estimate produced by Davis Langdon Everest,[7] the construction cost benchmark for the Drawn Study Seven is 11.56 $£.m^{-2}.a^{-1}$; this is almost three times the 'urban house in paradise' benchmark. As the dwelling is constructed from timber frame in prefabricated elements, it is plausible that if the number of dwellings were significantly increased, on this site or elsewhere, this value could be reduced through economies of scale.[8] In lifecycle utility costs, the drawn study did not achieve the performance of the 'urban house in paradise'. The use of electricity for the majority of fuel consumption had a detrimental impact upon the lifecycle cost benchmark, despite achieving the Energy Consumption: Inhabitation benchmark; however the discrepancy is small, the drawn study benchmark being 7.96 $£.m^{-2}.a^{-1}$, as opposed to the 'urban house in paradise' benchmark of 7.36 $£.m^{-2}.a^{-1}$. Because the mains water element of the Water Consumption: Inhabitation benchmark was above its target, due to insufficient area of collecting surfaces which is discussed under 11.3.8, the cost benchmark was also not achieved, being 124 $£.p^{-1}.a^{-1}$, as opposed to the benchmark of 97.85 $£.p^{-1}.a^{-1}$.

However, over the life span of the dwelling, the cost saving achieved through the reduction in energy and water consumption is significantly more, by a factor of 2.5, than the difference in capital construction cost between the drawn study than one constructed to the performance of a typical dwelling of the same size.[9]

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[6] For example 'Band A' appliances in the standard European grading system.
[7] Refer to cost summary in analysis of Drawn Study Seven and Eight, in volume 2.
[8] The extensive use of prefabrication in Holland has lead to construction cost reductions of up to 15 percent over comparable buildings in the United Kingdom. Moerkerken, Han. '... and how much does this cost?', *Building*, 8 September 2000. The adoption of similar methods would reduce the construction cost of the drawn study to 9.82 $£.m^{-2}.a^{-1}$.
[9] Refer to Lifecycle Cost analysis in Benchmark Analysis of Drawn Studies Six, Seven and Eight by Manual Calculation in volume 2.

11.3.6 Quality of Internal Environment - Air Tightness

As the air tightness can only be measured after a dwelling is constructed, this benchmark value is validated on precedent. Examples of best practice in dual timber frame construction were researched to determine an appropriate value for the dwelling.

This benchmark is a design and construction benchmark, as it could not be validated until after completion of the dwelling. In the drawn study this raised the question of how well a timber framed structure would be able to perform in terms of air tightness, particularly as it is a dry construction method, and wet methods, such as brick and block, are generally recognised as more air tight. Because post-completion testing is the only way in which to determine the actual air tightness, precedent was used to determine how best practice construction can perform, and to adopt this value. In a 1991 detached, two storey house in St Gallen, Switzerland the air leakage was measured at 0.17 $ac.h^{-1}$ at 50 Pa,[10] which is the benchmark of the 'urban house in paradise', proving that it is achievable in timber frame construction. The principal way in which this was achieved was through the specification of an air and vapour barrier, fitted with great care, to prevent heat loss from wind penetration. Similar standards have been achieved in other timber frame dwellings, including the 1978 House B in Hjortekaer, Denmark, which achieved a post-completion air tightness of 0.2 $ac.h^{-1}$ at 50 Pa. The 1983 Duncan House in Victoria, Canada achieved an air tightness of 0.5 $ac.h^{-1}$ at 50 Pa.[11] It was considered valid to use the lowest of these three values, as the dwelling is the most recent, and therefore could adopt better practices of construction.

11.3.7 Quality of Internal Environment: Daylight

As the drawn study is a mid-terrace dwelling with a strong orientation to one aspect, it did not achieve the Daylight benchmark, although it was above that of the typical semi-detached dwelling.

The area of glazing on the south aspect of the dwelling was maximised to raise both passive solar gains and the Daylight benchmark. However balancing the area of glazing on the north wall with heat loss, as the thermal performance of glazing is much worse than that of the wall, has reduced the benchmark to 3.5; therefore the drawn study did not achieve the 'urban

[10] A similar construction technology was used to that proposed for the drawn study; external walls were constructed in timber frame with 300mm insulation, finished externally in timber cladding; floors were suspended timber; windows were double glazed in timber frames. BRECSU. Op. Cit.

[11] The dwelling was constructed with a timber frame wall, 300mm of insulation, and finished in timber cladding; floors were suspended timber and windows double glazed in wood frames; a polyethylene vapour barrier was also specified. Ibid.

house in paradise' benchmark of 5 for living spaces. However, the value is significantly above 2.5, the benchmark for a typical semi-detached dwelling. As the value could be potentially achieved in other design solutions and contexts it was considered that the 'urban house in paradise' benchmark should not be reduced.

11.3.8 Water Consumption: Inhabitation

Although the dwelling achieved the overall water consumption benchmark, with a limited area of surfaces for collecting rainwater it did not reduce the use of mains water to the benchmarked level. As the second case study demonstrated that the benchmark could be achieved, it was considered that because the drawn study could not do so this fact did not constitute sufficient reason to raise the value.

The analysis shows that the benchmark may prove difficult to achieve, due to the area of collecting surfaces that is required. For example, if the overall consumption benchmark of 38.3 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:[12]

$$\text{Area } (m^2) = (x \times n \times 365.25) / (r \times 0.66)$$

where, x = daily water consumption per person ($l.p^{-1}.d^{-1}$)
n = number of inhabitants in the dwelling
r = annual rainfall (819 mm in Manchester) (mm)

This gives a roof area of 61.5 m^2. If the requirement is based upon the designed occupancy level of the drawn study, which is the maximum demand that might be expected, this gives a worst-case scenario. On the basis of five inhabitants, the roof area required would be 128.1 m^2. The roof area of a typical 3 bedroom semi-detached dwelling is in the region of 49 m^2, and was 70.2 m^2 for Drawn Study 4 and 55.1 m^2 for Drawn Study 7. This demonstrates that a dwelling will struggle to obtain the benchmarked water consumption from rainwater collection from its roof. However, in itself this does not constitute sufficient reason to increase the mains water consumption benchmark; as it stands it will provide an incentive for utilising collection and supply of other sources of rain and grey water, such as run-off from hard landscaping and waste water within the dwelling, to achieve the benchmark.

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[12] Derived from Vale, Brenda and Robert. *The Autonomous House – Design and Planning for Self-Sufficiency*, London: Thames and Hudson, 1975.

11.3. Thermal Mass

The use of timber frame to reduce the embodied energy means that the drawn study dwelling has a very low thermal mass, which could affect the beneficial utilisation of internal heat gains and the comfort of the inhabitants. In conjunction with the validation by specialist interviews this has lead to the proposal of a benchmark for thermal mass, which would require a subsequent review of the Ecological Weight: Embodied Energy benchmark.

The pursuit of the Ecological Weight: Embodied Energy benchmark had a significant influence on the decision to use timber frame as the construction method for the dwelling. However, the use of a thermally 'lightweight' structure can have disadvantages. Whilst the structure is quick to warm up (as the thermal capacity is low so that the vast majority of the input by the heating system will go into heating the internal space of the dwelling), it is also quick to cool down, as no heat is stored within the fabric. This could be seen as an advantage in a dwelling occupied intermittently, which one in a city centre is likely to be as the inhabitants would be out at work during the day. However, in a dwelling designed to maximise solar heat gains and one with very little fabric heat loss (so that intermittent gains from appliances and occupants become significant), this could lead to overheating as in a low-mass dwelling there is little thermal capacity to absorb the excess heat. The comfort of the dwelling's inhabitants is a crucial factor, as it can play a significant role in the life span of the dwelling. In a high-mass dwelling, with for example a concrete slab ground floor, concrete beam and block upper floors, and an internal structure of dense concrete, the mass can absorb and store these incidental gains, and release them over a period of time maintaining the internal temperature at a steady level. Therefore, whilst taking longer to heat up in the first instance, the high mass dwelling will maintain a more consistent internal temperature over a period of time, and be more suited to absorbing and releasing incidental heat such as solar gains. Szokolay comments that, "The indoor conditions will be more stable [for a massive building] than in a thermally lightweight building"[13]

The analysis of Drawn Study Eight, to determine the Ecological Weight: Embodied Energy benchmark by manual calculation can be used to establish the thermal capacity of the dwelling. The thermal capacity of other construction technologies can then be determined for the same design, and the tool used to determine how these other technologies perform

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[13] Szokolay, S. *Environmental Science Handbook*, London: The Construction Press, 1980.

against the Ecological Weight: Embodied Energy benchmark. The total volume of the materials on the warm side on the insulation can be derived from the manual calculation of the Ecological Weight: Embodied Energy benchmark, (refer to volume 2). This will include the ground floor and internal floors, the plaster and plasterboard on all surfaces, the timber frame on the internal leaf of the structure, the lower section of the roof joists, and the internal pane of glazing. From the total volume for each material, the density can be used to calculate the mass; the specific heat capacity of each material[14] can then be used to calculate the heat capacity for each material, and these values summed results in the total heat capacity of the dwelling. The total of 17.53 $MJ.K^{-1}$ can be translated into a value per unit floor area of 0.141 $MJ.K^{-1}.m^{-2}$, or 0.039 $kWh.K^{-1}.m^{-2}$.

A high-mass variant for the drawn study was also explored. The total of 109.04 $MJ.K^{-1}$ can also be translated into a value per unit floor area of 0.879 $MJ.K^{-1}.m^{-2}$, or 0.244 $kWh.K^{-1}.m^{-2}$. From these two scenarios, it can be seen that the high-mass variant of Drawn Study Seven has a thermal capacity over six times higher than that of the low-mass variant. The thermal capacity of a mid-mass variant was also studied. The total of 36.83 $MJ.K^{-1}$ for the mid-mass variant can also be translated into a value per unit floor area of 0.297 $MJ.K^{-1}.m^{-2}$, or 0.083 $kWh.K^{-1}.m^{-2}$. Following this the embodied energy of the materials in each of the three variants was calculated.

Variant	Heat Capacity of Dwelling (MJ.K-1)	Embodied Energy of Dwelling (kWh.m-2)
Low Mass	17.53	306.0
Mid Mass	36.83	369.6
High Mass	109.04	576.7

Table 14: Heat capacity and embodied energy of low-, mid- and high-mass variants of Drawn Study 7

The thermal mass of the mid-mass variant is approximately double that of the low-mass, with an increase in embodied energy of one fifth. More notably, the thermal mass of the high-mass variant is over six times that of the low-mass, however, the level of embodied energy has only doubled. This brief analysis suggests that the thermal mass increases at a faster rate than the increase in embodied energy.

[14] The values for specific heat capacity are taken from Serway, Raymond A. *Physics For Scientists & Engineers*, London: Saunders College Publishing, 1990; and Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.

Vale and Vale conclude that a massive approach to the building fabric is all but a necessity in low energy design, as it makes the best utilisation of all available heat gains, but at the same time acknowledge that the embodied energy of that dwelling will be significantly higher.[15] This is borne out in the analysis above. Also, the timber frame design of Drawn Study Seven will mean that virtually all of the materials can be derived from recycled or renewable sources, which would not be achievable to the same degree for a high thermal mass dwelling. Yet also in favour of the high-mass solution is that an airtight structure is easier to achieve in masonry construction. This is a notable example of how the most sustainable solution can be a complex result to determine, with many different parameters to consider.

One function of the tool is that it enables a designer to determine the most sustainable solution by assessing a dwelling against the prioritised benchmarks. In the Drawn Study the use of timber frame enabled the Ecological Weight: Embodied Energy benchmark to be achieved; however, to establish it its thermal mass is sufficient further research would have to be undertaken to determine the relationship between the mass and energy consumption during inhabitation. From the analysis carried out above it is possible to propose a benchmark for the thermal mass of the dwelling. The Ecological Weight: Embodied Energy benchmark would then ensure that the construction technology used to achieve the thermal mass did not exceed a benchmarked level. Evidently a benchmarked increase in the thermal mass of the dwelling's envelope would require that the Ecological Weight: Embodied Energy benchmark be increased so that more massive technologies could be used. The critical issue will be at what level does the increase in thermal mass cease to provide benefit of reduced energy consumption over increased embodied energy. It has been determined that the substitution of a concrete slab floor for the traditional timber floor in timber frame dwellings in New Zealand would reduce the space heating demand by 40 percent.[16]

A value is proposed for a thermal mass benchmark in section 12.4, in chapter 12, Conclusions. However, within the remit of this research study it is not possible to determine to what extent the thermal mass would affect the energy consumption of the dwelling, and therefore to prioritise it against the parameters of ecological degradation to determine its place in the criteria's hierarchy. If the benchmark was then integrated into the assessment

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[15] In their comparative analysis of hypothetical low mass and high mass rooms, they note that the energy embodied in transporting materials to site will, all else being equal, be 23 times higher for the high mass room. Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*.

[16] Breuer D. *Energy and Comfort Performance Monitoring of Passive Solar, Energy Efficient New Zealand Residences – Report Number 171*, Wellington: New Zealand Energy Research and Development Committee, 1988; in Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*.

tool, a balance could be struck between the thermal mass and the embodied energy of the dwelling, accounting for the relative significance in the overall ecological sustainability of the dwelling.

11.4 The Tool

The benchmarks assessed by the tool were also determined by longhand calculation; the degree of correlation between the two methodologies was used to validate the accuracy with which the tool evaluated the benchmarks. The greatest variation between the values was 7 percent; the majority were within 3 percent.

The performance of Drawn Studies Seven and Eight was determined in two ways: data was entered into the assessment tool and they were also measured through longhand calculations. The purposes of this exercise were twofold; firstly to ensure that the algorithms in the tool were correct (as discrepancies between the values for each method would highlight possible errors); secondly, where possible, the longhand calculations used a different methodology, and the correlation between the two was noted. This assisted in determining how accurately the tool was predicting the benchmarks.

Criteria	Benchmarks		
	Tool	Longhand	Variation (%)
Energy Consumption: Inhabitation	24.26	24.17	0.4
Energy Generation: Inhabitation	25.0	25.25	1
Q of I E: Ventilation and Air Tightness	0.45, 0.17	0.45, 0.17	0
Ecological Weight: Embodied Energy	306.0	312.7	3
CO_2 Emissions: Inhabitation	13.8, -1.36	13.5, -1.40	2
Design Life Span	120	120	0
Pollution: Energy Consumption Inhabitation	5.945, -0.720	5.947, -0.766	0.1
Thermal Performance: roof	0.08	0.078	3
Thermal Performance: walls	0.12	0.112	7
Thermal Performance: ground floor	0.10	0.093	7
Thermal Performance: doors	0.8	-	-
Thermal Performance: windows	0.55	-	-
Ecological Weight: Embodied CO_2 Emissions	107.1	109.4	3
Other Greenhouse Gas Emissions	0	0	0
Water Consumption: Inhabitation	38.3	38.3	0

Table 15: Benchmark performance of Drawn Studies 7 and 8 as determined by 'urban house in paradise' assessment tool and manual calculation.

The benchmark values for embodied energy and consequent embodied CO_2 determined by the assessment tool and long hand calculation have a variation of 3 percent between each other. The long hand calculation was determined using a different methodology; Drawn Study Eight was scrutinised to determine the exact quantity of material used to construct the dwelling, and from those values the embodied energy, and consequent embodied CO_2, was calculated. The discrepancy of 3 percent between the values determined by the tool and those based upon the exact quantity of material in the drawings is considered statistically more than acceptable, and gives confidence that the tool is predicting the Ecological Weight: Embodied Energy and Embodied CO_2 benchmarks with a reasonable degree of accuracy.

The benchmark values determined by the tool and longhand calculation for Energy Consumption: Inhabitation are within 1 percent of each other. The discrepancy could be attributed to rounding of decimal places during the long hand calculation, as the spreadsheet carries the calculation to many more decimal places, and for that reason is the more accurate value. The largest variation, of 7 percent, for the thermal performance of the walls and ground floor is due to differences of 0.01 and 0.007 $W.m^{-2}.K^{-1}$ between the tool and longhand calculations. These could also be attributed to rounding during the calculation process.

The relatively high degree of correlation between the values determined by the assessment tool and longhand calculation give confidence that the algorithms within the tool are correct, and that the spreadsheet does not contain errors. To be certain of this a similar exercise, beyond the scope of this thesis, should be undertaken for other construction technologies, as not all sections within the tool have been validated, such as the thermal performance and embodied energy for masonry construction.

11.5 Specialist Interview

The validation by specialist interview sought the opinions of an architect and building services engineer on the tool, once they had conducted an assessment using it. The interviews were structured though a questionnaire, a critical format that ensured consistency between them.

Two interviews were conducted as a part of the validation process.[17] By choosing both an

[17] Ian Wroot 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

architect and a services engineer the scope of the validation process was enlarged and therefore more comprehensive; for example the architect assessed the tool in terms of its appropriateness to the design process and from the perspective of a designer, and the services engineer assessed the mathematics of the tool's methodology and its accuracy.[18]

Both validators were briefed on the background to the research, the methodology of the assessment and how to utilise the tool, and were then left to use it in spreadsheet format to conduct an assessment. The worksheet format was referred to for demonstrating the algorithms used within the tool. To maintain consistency and objectivity between both interviews, a questionnaire formed the framework for the validation process. The completed questionnaires can be seen in Annexe 6.0 (refer to volume 3). The aim of the validation appraisal was for the validators to rate the performance of the tool in terms of, for example, its ease of use, accuracy and relevance; also to record opinions upon, for example, areas of particular significance or ambiguity in the tool's assessment process, as well as potential revisions or improvements that could be made.

11.5.1 Validation by Brundrett, Building Services Engineer

That embodied energy was shown to be a significant factor was considered to be of particular significance, and also that the tool highlights infiltration. In terms of accuracy Brundrett identified the ventilation analysis and lack of account for thermal mass as potential problem areas. Overall the tool was considered as a valid way of assessing the fabric element of a dwelling's design.

Although the first impression of the assessment tool was that it appeared complex, it was acknowledged that much of the information required arises in the duration of the design process; hence the rating above the median value, between poor and excellent, in terms of ease of use. This also related to the view on the time taken to conduct an assessment. Although at two hours the process is perceived as time consuming, a significant quantity of the data required would be produced for the statutory SAP rating, and the additional information required is therefore reduced to a minimum; this is further aided by the use of

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perspective of a project architect. Geoffrey Brundrett 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.

[18] The interview with Brundrett was conducted on 18 September 2000; the interview with Wroot was conducted on 21 September 2000.

default settings on the computer spreadsheet. It could reasonably be speculated that, with practice, the assessment time would be reduced, as the user becomes more familiar with the procedure. Despite this, in view of the detailed nature of the outcomes of an assessment, two hours was rated as acceptable.

In overall terms the probable accuracy of the tool's assessment was also considered acceptable. Three potential problem areas were identified: the energy consumption during inhabitation being considered as an independent factor rather than as a dependant one; the ventilation analysis; finally that the potential significance of thermal mass in ultra low energy design is not accounted for. The former point relates to the prioritising that determined the weightings used to determine the hierarchy of the criteria, and in the scoring of the assessment tool. Because the energy consumption during inhabitation is dependent upon factors such as the thermal performance of the fabric and the air tightness of its structure, Brundrett considered that it should not be included in the hierarchy of the criteria as this might be considered as double counting their contribution. However, because the hierarchy has been determined on the basis of the individual contribution of each of the criteria, this would not affect the actual order of the criteria, only the relative magnitude of their weightings. Furthermore, the individual prioritising of ventilation, air tightness and thermal performance calculates the reduction in ecological impact that achieving these benchmarks individually would make, whilst the Energy Consumption: Inhabitation considers the reduction in impact by achieving its benchmark by whatever means. This issue does not affect the calculation of the Energy Consumption: Inhabitation benchmark itself.

The ventilation analysis is identified both as a potentially problematic area in terms of the accuracy of the assessment, and as an area which the tool should assess but does not. The assessment of the ventilation rate is based on the method used in the Standard Assessment Procedure's worksheet; Brundrett considers that this to be crude in relation to the overall accuracy of the tool. The suggestion was made that the ventilation rate calculation be expanded to be more elaborate, which will contribute to the probable accuracy of the assessment. This is particularly relevant due to the increased significance of the heat loss due to ventilation in low energy dwellings. Also identified as a specific potential improvement would be extending the assessment to include a more detailed analysis of ventilation systems with heat recovery. The suggestion was also made that the infiltration rate and ventilation be separated in the prioritsing of the criteria, which has been undertaken, refer to chapter 7.0.

Related to the suggestion that ventilation is an element of the dwelling's performance that should be assessed in more detail are health implications, which are also recommended by

Brundrett for inclusion. Particularly in an urban context, where air pollution levels are relatively high, the rate and control over ventilation, including filtration, can affect the internal air quality of the dwelling. Also related to health, and to ventilation of an air tight dwelling, through the quality of the internal environment, is condensation. Health is an aspect that, if the parameters used in prioritising the criteria were expanded upon, to include social as well as ecological sustainability, in terms of quality of life and well being, it would become more significant. It would also be a criterion that could be used, at least in part, to quantitatively benchmark a qualitative criterion, which quality of life and well being arguably are.

It was recognised by Brundrett that the thermal mass of the fabric was not accounted for in terms of its contribution to the energy consumption of the dwelling during inhabitation, which is becoming an important factor in low energy design; whereas it is accounted for in terms of its embodied energy. It was suggested that, as a potential improvement, the tool could be extended to measure the benefit for thermal mass achieved through heavy construction.

The embodied energy analysis was considered to be an area of particular significance in the tool's assessment methodology. This was primarily due to the fact that the tool identifies the quantity of embodied energy to be a significant factor in the lifecycle energy consumption of the dwelling, and that in the past this fact has been overlooked in considering the environmental performance of buildings. The significance given to the air tightness of the dwelling's envelope was also considered very appropriate, due to the proposed revisions to the Building Regulations which include incorporating minimum infiltration rates through pressure testing performance standards.

The only additional comments made were that the relationship between insulation level and consequent energy consumption used in the SAP methodology may need refining when extended to very low energy buildings. In measured tests performed by BRECSU, who monitor and revise the SAP procedure, the correlation between predicted and measured consumption is within 10 percent; however, this may not include low energy dwellings.[19] Following the interview it was considered that this issue warranted further study within the scope of the research. The accuracy of the SAP methodology for low energy dwellings was determined by using the thermal performance and specification values of an ultra low energy dwelling in the SAP assessment, to determine if the predicted energy consumption is comparable to the value measured when the dwelling had been built and monitored.

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[19] Personal communication with Dr Brian Anderson, BRECSU, 7 August 2000.

Data for the Vale's dwelling in Southwell was used in the SAP worksheet.[20] The predicted energy consumption for space and water heating was 21.3 $kWh.m^{-2}.a^{-1}$; the measured energy consumption during occupation was 18.8 $kWh.m^{-2}.a^{-1}$.[21] Rational deduction suggests that the discrepancy of 2.5 $kWh.m^{-2}.a^{-1}$ could be attributed to the lower than typical mean internal temperatures of the Southwell dwelling during winter.[22] These temperatures should be seen against the context of steadily increasing average internal temperatures in the United Kingdom's dwellings.[23] The SAP assessment assumes a mean internal temperature, based on empirical research. This determines the space heat requirement, taking account of internal gains and losses through fabric, ventilation and infiltration. As the typical internal temperatures of dwellings, based on empirical research, are higher than those of the Southwell dwelling, this would account for the higher predicted energy consumption by the SAP method, which assumes that energy is consumed in maintaining the dwelling at a higher temperature than was in fact the case. This brings forward the complex issue of acceptable internal temperatures for dwellings. The internal temperature of a dwelling is a lifestyle decision; clearly the Vales are willing to live in a dwelling that is cooler than typical. This is an issue over which the designer has little control, therefore if seems reasonable to assume that the value predicted by the SAP methodology is appropriate, as it is based on empirical data and therefore more likely to predict the internal conditions of unknown inhabitants. For a tool that is predicting the likely energy consumption of a dwelling, it would be more robust to use a methodology based on observed data, which includes a statistical range of mean internal living temperatures. A possible amendment that could be made to the tool in this respect would be to allow the user to vary the assumed mean internal temperature.

Overall, as a way in which to assess the performance of a dwelling, Brundrett rated the tool above the median value, towards 'excellent', based particularly on the thoroughness of the building fabric assessment of the dwelling, such as the thermal performance and embodied energy and consequent emissions. He concludes that the tool is a valid way of assessing and ranking the fabric parts of a building design.

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[20] Refer to Case Study Two, 5.2.

[21] Vale, Robert and Brenda. *The New Autonomous House – Design and Planning for Sustainability*.

[22] The lowest measured monthly average dry-bulb air temperature in the dwelling, in February 1995, was 15 °C which was in the bedrooms; in the living room this was 17.5 °C in March 1996. Ibid.

[23] Research demonstrates that since the end of the 1940s, average internal winter temperatures have been rising, from 14.3 to 18.6 °C in the 1980s. Lowe, R., J. Chapman and R. Everett, 'The Pennyland Project', *ETSU Report E5A/CON/1046/174/040*, Oxford: Energy Technology Support Unit, 1985. The reasons for this could be manifold, including the increase in the number of dwellings with central heating installations and the tendency to wear fewer layers of clothing.

11.5.2 Validation by Wroot, Architect

The assessment of embodied energy and energy consumption by appliances were identified as areas of particular significance. Although Wroot did not consider any areas to be redundant, he thought the tool appeared potentially onerous. It was suggested this could be overcome by improving the interface, 'nesting' the assessment so that various depths of assessment could be undertaken.

In terms of ease of use, Wroot rated the tool with a median, or acceptable, value primarily due to the large quantity of data required for the assessment. The suggestion was made that a hierarchical system could be incorporated to improve the user interface with the tool; this would mean 'nesting' the data input so that various levels of assessment could be made, with more detailed information required only for more advanced assessments. Initially a rapid assessment could be made on the basis of default assumptions for much of the data, which might only require details such as the size of the dwelling, the number of occupants, and basic servicing information. More detailed assessments could be conducted by moving to other pages to increase the data input, increasing the specificity of the assessment profile, and therefore the accuracy of the predicted benchmarks. This would also respond to Wroot's opinion that the assessment appears very advanced, and therefore time consuming, for general use by architects, as a consequence of which it receives its lowest rating, for the time taken to conduct an assessment. Yet whilst it was thought that the tool might be onerous in places, Wroot did not consider any areas of the assessment to be redundant. Creating levels to the depth of assessment undertaken is the only improvement identified that could be made to the tool.

The accuracy is rated above acceptable, although it is acknowledged by Wroot that the tool would have to be pitted against traditional long hand calculations.[24] A repeat assessment using the tool produced the same results, demonstrating that the methodology is consistent.

As for Brundrett, the embodied energy calculations of the dwelling's fabric were seen as an area of particular significance, as were those relating to the energy consumption by appliances. These were identified as tackling issues that Wroot has not seen in assessment models before, validating this as a contribution to knowledge in environmental assessment.

[24] This has been conducted as another part of the validation process, and is commented on above.

Even the raw data on appliance consumption was perceived as valuable in its own right, although verification of the sources was seen as required.[25]

In overall terms, as a way in which to assess the performance of a dwelling, the tool is rated by Wroot above the median value. It is highlighted again that the flexibility in use so that a quick assessment can be made early in the design process on minimal data input, followed by more detailed assessment as further design data becomes available, would be a great benefit. Wroot commented that the design of the interface between the tool and the user might be more suited to a software designer, who could take the existing version of the assessment tool and create a more accessible interface.

11.5.3 Conclusions from Specialist Interviews

Both validators confirm the relevance of the tool, and therefore of the research. The weakest element was the time taken to undertake an assessment, although Brundrett recognises that a significant proportion of the data is required in any case for the statutory SAP assessment. The latter point could be resolved through improving the interface and greater use of defaults. Taken in all the tool was viewed as being superior to the statutory SAP assessment.

The responses that were rated numerically are summarised in the following table. The valuation was between 1 and 5, with 1 representing a poor performance, 5 a high performance and a median value as acceptable.

Parameter of questionnaire	Score
Ease of use	3.5
Time taken to conduct assessment	2.5
Probable accuracy of assessment	3.5
Relevance to current drives for innovation	4.5
Overall success of tool as assessment method	4

Table 16: Combined scores from specialist interview

[25] The basic information on typical appliance consumption on the basis of floor area was determined by translating data from the BREDEM assessment; however, to take account of increased efficiency in appliance specification, these values were extrapolated through the scenarios of zero CO_2, zero heating and autonomous dwellings in *GIR 53*, as a part of the research. The specific values of appliances is based on empirical studies also conducted as a part of the research; this allows the designer to more accurately predict the consumption of the dwelling on the basis of the appliances that are likely to be included, and to account for the specific use of low energy consumption appliances.

Both validators recognised that the tool is relevant to the drives for innovation that are currently being promoted in the house building industry, and is testimony to the appropriateness of the research. This quality scored the highest. Whilst considered 'acceptable', the poorest facet of the tool is the time taken to undertake an assessment. However, Brundrett recognised that a significant proportion of the data required is needed for the mandatory SAP assessment, and Wroot suggests that this could be resolved by decreasing the initial amount of information initially required. On a broader level, if the training of architects increased the understanding of a dwelling or building in terms of the performance criteria, the data would be more easily identifiable.

Improving the interface between the user and tool could be achieved through an increased use of defaults. Creating nesting in the levels of assessment depth, through either on-screen menus or pages of the assessment that can be accessed as desired in order to update default assumptions on performance, would achieve a hierarchy to the information required. This would also mean that the potential extent of the assessment tool is not seen immediately one opens the spreadsheet, which led to the comments that it initially looked 'fearsome' and 'onerous'. Reducing the time for an initial, broad-brush assessment would also increase the commercial appeal of the tool, and therefore its likely adoption as a part of the design process. The scope of the work has not enabled this to be undertaken, and therefore it is recognised as a potential area of further research.

11.6 Summary

The correlation between the benchmarks determined by the tool and those derived through literature review and longhand analysis give confidence in the values and methodology of the assessment tool. This assurance is echoed in the responses of the specialists interviewed as a part of the validation process. Although not all the benchmarks were achieved in the drawn studies, it was not considered that the values should be revised for this reason. Thermal mass was considered as an additional criterion, which would have a consequential impact upon the embodied energy and CO_2 benchmarks.

The relatively high degree of consistency between the benchmarks determined through the assessment of a typical three bedroom semi-detached dwelling using the tool and those derived through literature review give confidence in the accuracy of both those values and the tool's methodology. It is identified that the embodied energy and CO_2 assessment, which at present measure the energy embodied in the envelope, floors and foundations of the dwelling, could be elaborated to account for materials not within the fabric of the dwelling, such as internal services.

Although not all the benchmarks were achieved in the drawn study, the analysis did not determine adequate justification that each benchmark could not be met in another situation, and therefore did not constitute sufficient reason for altering the benchmark values for those criteria. However both the validation by the drawn study and specialist interviews have identified that the thermal mass of the structure is a factor in the dwelling's performance that should be included in the assessment. Raising the thermal mass from the level achieved in the drawn study will have a subsequent impact upon the Ecological Weight: Embodied Energy and Embodied CO_2 benchmarks. Therefore in conjunction with establishing an appropriate benchmark for thermal mass, the embodied energy and CO_2 benchmarks should also be increased to establish a value so that thermally massive construction technologies are not ruled out, but that the embodied energy and CO_2 of traditional masonry construction is still innovated upon. A potential value that might reconcile these ambitions is proposed in section 12.3.2 in the Conclusions.

The correlation between the values determined by the assessment tool and longhand calculation give confidence that the algorithms within the tool are correct, and that the spreadsheet does not contain errors. To be certain of this, a similar exercise will be undertaken for other construction technologies outside the scope of this thesis, as not all sections within the tool have been validated, such as the thermal performance and embodied energy steps for masonry construction.

The relevance of the assessment tool to current drives for innovation in the house building industry was commented upon in both specialist interviews. Although 'acceptable', the poorest facet of the tool was considered to be the time taken to undertake an assessment. This could be resolved by decreasing the initial amount of information initially required through an increased use of defaults and improving the interface between the user and tool. The ease of use, accuracy and overall success of the tool were all rated above acceptable.

In addition to the specialist interviews, the tool was demonstrated to Suzy Edwards and Jane Anderson at the Sustainable Construction Unit of the Building Research Establishment, during a visit to discuss the *Envest* assessment tool for office buildings which was developed there.[26] A positive response was received for the 'urban house in paradise' assessment tool as a valuable development in assessment techniques. Of particular interest was that the benchmarks had been quantified in dimensional terms, allowing a valuable insight into the performance of the dwelling in real terms rather than solely in terms of a final score.

With the analysis and validation complete, conclusions on the research could be drawn, in particular on the criteria, their benchmarks and assessment tool. It was also possible, through hindsight, to consider if there are other criteria that could be encompassed in the performance of the 'urban house in paradise'. Finally it could be brought to conclusion as to whether the holistic benchmarked criteria defining the performance of urban dwellings is a viable and valid concept.

[26] This took place at the offices of the Sustainable Construction Unit of the Building Research Establishment on 16 August 2000.

The Performance Benchmark Assessment Tool

Dimensional Information	Data		Data		Answer
Ground floor - Area (m2):	36.5	Ceiling height (m):	2.3	Volume (m3) =	83.95
First floor - Area (m2):	36.5	Ceiling height (m):	2.3	Volume (m3) =	83.95
Second floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
Third floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
Fourth floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
Subsequent floor - Area (m2):		Ceiling height (m):		Volume (m3) =	0
Number of storeys:	2			Total floor area (m2) =	73
Dwelling perimeter (m):	27.92			Total volume (m3) =	167.9
Building height (mean wall height) (m):	5			Space standards: Area (m2.p-1) =	14.6
Designed occupancy level:	5			Space standards: Volume (m3.p-1) =	33.58
Ventilation					
Number of chimneys:	0				
Number of flues:	1				
Number of fans and passive vents:	1				
Air Tightness target benchmark:	13	Refer to Table A for comparable benchmarks of air tightness		Total infiltrtration =	0.678677784
Number of sheltered sides:	2	Enter '2' if unknown		Shelter factor =	0.85
Mechanical ventilation? Yes=1, No=0:	0			If mechanical ventilation, vent rate =	1.076876117
If no heat recovery, enter 0.33:	0.33				0.576876117
Natural ventilation? Yes=1, No=0:	1			If natural ventilation, vent rate =	0.666393027
				Ventilation rate =	0.67
U-Values					
For surface resistances (R values), refer to Table B		For thermal conductivity of materials, refer to Table C			
U-Roof					
Outer finish - Thickness (m):	0.05	Conductivity (W/m.K):	0.245		
Waterproof layer - Thickness (m):	0.0025	Conductivity (W/m.K):	0.6		
Sheathing material - Thickness (m):	0	Conductivity (W/m.K):	1		
Outer structure - Thickness (m):	0.1	Conductivity (W/m.K):	0.14		
Insulation - Thickness (m):	0.2	Conductivity (W/m.K):	0.04		
Inner structure - Thickness (m):	0.1	Conductivity (W/m.K):	0.14		
Inner finish - Thickness (m):	0.012	Conductivity (W/m.K):	0.46		
Rso:	0.05				
Rcav:	0.17				
Rsi:	0.12				
Roof pitch (degrees):	47				
Is insulation laid in plane at pitch to ceiling? Yes=1, No=0:	0				
Is insulation laid in plane parallel to ceiling? Yes=1, No=0:	1				
Is roof solid construction? Yes=1, No=0:	0				0.149395562
Is roof timber construction? Yes=1, No=0:	1				0.250365877
Joist width (m):	0.05	Joist centre to centre (m):	0.6	U-Roof =	0.25
U-Wall					
Outer finish - Thickness (m):	0	Conductivity (W/m.K):	1		
Outer leaf - Thickness (m):	0.1	Conductivity (W/m.K):	1.21		
Sheathing material - Thickness (m):	0	Conductivity (W/m.K):	0.14		
Insulation - Thickness (m):	0.04	Conductivity (W/m.K):	0.034		
Inner structure - Thickness (m):	0.1	Conductivity (W/m.K):	0.14		
Inner finish - Thickness (m):	0.012	Conductivity (W/m.K):	0.46		
Rso:	0.05				
Rcav:	0.18				

Rsi:	0.12				
					0.425624667
Is wall solid construction? Yes=1, No=0:	1				
Is wall timber frame construction? Yes=1, No=0:	0				0.632837052
If timber frame, stud width (m):	0.05	Stud centre to centre (m):	0.6	U-Wall =	0.43
U-Ground					
Is floor a non-suspended floor? Yes=1, No=0:	1	Is floor a suspended floor? Yes=1, No=0:	0		
Are only 2 parallel edges exposed?	0	Are only 2 edges at right angles exposed?	0		
Does floor have only single exposed edge?	0				
Joist/beam (If applicable) - Depth (m):	0	Conductivity (W/m.K):	0.15		
Joist/beam - Width (m):	0	Joist/beam centre to centre (m):	0.6		
Screed - Depth (m)	0.05	Concrete slab - Depth (m):	0.3		
Hardcore - Depth (m):	0.3				
Deck or slab - Thickness (m):	0.2	Conductivity (W/m.K):	1.44	β =	1.367636561
Insulation - Thickness (m):	0.04	Conductivity (W/m.K):	0.035		0.313084112
External wall thickness (m):	0.3	Thermal conductivity of earth (W/m.K), or 1.4:	1.4	Corrected length =	8.025
Floor length (greater dimension) (m):	8.025	Floor breadth (lesser dimension) (m):	5.025	Correctedbreadth =	5.025
Rsi:	0.12				
				Unonsuspended =	0.433448268
				Ususpended=	0.185643971
				U-Ground =	0.43
U-Windows					
Independent manufacturer's U-value for glazing:	3.3			U-Window and Rooflight =	3.3
U-Doors					
Independent manufacturer's U-value for doors:	3.3			U-Door =	3.3
Heat Loss Parameters					
Roof area (excluding openings) (m2):	48.6				
External wall area (excluding openings) (m2):	82.84				
Party wall area (m2):	38.9				
Ground floor area (m2):	36.5				
Window area (m2):	12.82				
Rooflight area (m2):	0				
Door area (m2):	2.1				
Other element, area (m2):		U-value:			
				Total area of dwelling envelope =	221.76
				Ventilation heat loss =	36.92283845
				Heat loss coefficient =	149.4062293
				Heat loss parameter =	2.046660676
Water-heating Energy Requirements					
Is requirement on basis of consumption? Yes=1, No=0:	0	Is requirement on basis of floor area? Yes=1, No=0:	1		
On the basis of predicted consumption:					
Predicted hot water consumption (l.p-1.d-1) (Table O):	50	Temp difference between supply and heated (oC):	49	Energy requirement =	18.72947213
		36 oC if header tank is within insulated envelope, otherwise 49 oC		Distribution losses =	3.315116566
On the basis of floor area:					
Hot water energy requirement (Table O1):	6.17	Distribution losses (Table O1):	1.09		
Hot water storage volume (litres):	117	Storage loss factor (Table E):	0.0158	Actual energy requirement =	6.17
Primary circuit losses (Table F):	1.3	Efficiency of water heater (Table G1 or G2):	79	Actual distribution losses =	1.09
		Value should be adjusted by amount shown in 'efficiency adjustment' column in Table G3 and G5 where appropriate.		Energy for water heating =	13.17544304
				Heat gains from water heating =	4.93338
Internal Gains					
Are gains on basis of actual values? Yes=1, No=0:	0	Are gains on basis of floor area? Yes=1, No=0:	1		
On basis of actual values:					
Anticipated occupancy per week (hours), 90 or:	90			Metabolic gains =	307.1917808
Mean wattage of light bulbs (W), e.g. 13.5 or 80:	13.5			Lighting gains =	16.88655822

Total annual appliance consumption (kWh.a-1) (Table R)				Appliance gains =	0
Total annual cooking consumption (kWh.a-1) (Table R)				Cooking gains =	0
On basis of floor area:					
Lights, appliances, cooking and metabolic (W) (Table H):	431				
Additional gains (W) (Table H):	10			Actual met, light, app and cook gains =	431
				Water heat gains =	156.4374798
				Total internal incidental gains =	597.4374798
Solar Gains					
For solar flux, refer to Table I					
North facing - Area (m2):		Solar flux (W.m-2):			
North east facing - Area (m2):		Solar flux (W.m-2):			
East facing - Area (m2):		Solar flux (W.m-2):			
South east facing - Area (m2):	5.79	Solar flux (W.m-2):	26		
South facing - Area (m2):		Solar flux (W.m-2):			
South west facing - Area (m2):	1.63	Solar flux (W.m-2):	26		
West facing (m2):		Solar flux (W.m-2):			
North west facing - Area (m2):	5.87	Solar flux (W.m-2):	13		
Rooflights - Area (m2):		Solar flux (W.m-2):			
For solar access factor, refer to Table J; for new dwellings, if unknown, enter 1					
Solar access factor:	1			Solar gains =	269.23
For Utilisation Factor, refer to Table K				Total gains =	866.6674798
				Gains/loss ratio =	5.800745282
Utilisation factor:	0.95			Useful gains =	823.3341058
Mean Internal Temperature					
Mean internal temperature of living area (Table L):	18.85	Temperature adjustment (Table G5, if applicable):	0		
Heating system responsiveness, R (Table G1 or G4):	1				
Temperature difference between zones (Table M):	0.79				
Living room area (m2):	17.13			Mean internal temperature =	18.54752106
Degree Days					
				Base temperature =	13.03681304
Degree days (Table N):	1560				
				Useful energy requirement =	5593.769225
Water Consumption					
Refer to Table O to determine predicted water consumption					
Predicted consumption benchmark (litre/p/day):	160				
Rainwater storage (litres):	0			Storage ratio =	0
If storage ratio <1, enter value; if not, enter 1:	0				
Area of rainwater collection surfaces (m2):	48.6	Rainfall (mm.a-1) (Table P):	819		160
				Potable consumption =	160
				Rainwater consumption =	0
Energy Consumption - Inhabitation					
Space and Water heating energy consumption:					
Is heating by an individual system? Yes=1, No=0:	1	Is heating by a community system? Yes=1, No=0:	0		
		Does community heating have CHP? Yes=1, No=0:	0		
If by an individual system:					
Fraction of heat from secondary system (Table Q):	0				
Efficiency of primary heating system (%):	79	Efficiency of secondary heating system (%):	1	Primary space heating =	7080.720539
Values for efficiency of system from Table G1 or G2, adjusted by amount shown in 'efficiency adjustment' column in Table G3 and G5 where appropriate.				Secondary space heating =	0
If by a community system:					
Overall system efficiency:	100	Fraction of heat from CHP unit:		Space heating from CHP =	0
Distribution Loss Factor (Table O2):	1.1	Fraction taken from operational records or design specification		Space heating from boilers =	5085.24475

				Primary space heating =	7080.720539
				Secondary space heating =	0
Pumps and Fans consumption:				Water heating =	3659.845288
Number of central heating pumps:	1	Number of boilers with fan assisted flues:	1		
Warm air heating fans? Yes=1, No=0:	0	Full mechanical ventilation? Yes=1, No=0:	0	Pumps and fans =	175
Lighting and Appliance consumption:					
Is consumption based on actual values? Yes=1, No=0:	0	Is consumption based on floor area? Yes=1, No=0:	1		
If on basis of actual values:					
Mean wattage of light bulbs (W), e.g. 13.5 or 80:	13.5			Consumption =	147.92625
Total consumption of appliances (kWh.a-1) (Table R):	0			Consumption =	0
On basis of floor area:					
Lights and appliances (Table S):	3000			Lights and appliances =	3000
Cooking consumption:					
Total Cooking (kWh.a-1) (Table T):	656			Cooking =	656
				Energy Consumption: Inhab =	199.6104908
Energy Generation					
Photovoltaic Panels					
Annual solar energy availability, (kWh.m-2.a-1) :	1000	Efficiency of panel (%), or 19%:	19		
Refer to Table U for value by location, or 1000 kWh.m-2.a-1					
Area of photovoltaic array (m2):	0			Generation per annum =	0
Solar Water Panels					
Area of panel (m2):	0			Generation per annum =	0
Wind Turbines					
Average monthly windspeed (m.s-1) (Table U1):		Generator hub height (m):			
Roughness length (m), 0.4 m for urban areas:	0.4			Windspeed at hub height =	#NUM!
Annual energy yield:		Number of turbines:	0	Generation per annum =	0
Other sources (kWh per annum):				Generation per annum =	0
				Energy Generation: Inhab =	0
CO2 + Pollution Emissions - Inhabitation					
For CO2 emission factors, refer to Table V		For pollution emission factors, refer to Table W			
For individual heating systems:					
Primary space heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Gross CO2 emission =	57.94163943
Secondary space heating - CO2 emission factor:		Pollution emission factor:		Net CO2 emission =	52.83342767
Water Heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Gross Pollution Emissions - Inhab =	2.102452936
				Net Pollution Emissions - Inhab =	2.102452936
For community systems without CHP:					
Primary space heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Gross CO2 emission =	62.34073824
Water Heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Net CO2 emission =	60.84895741
				Gross Pollution Emissions - Inhab =	2.187359531
				Net Pollution Emissions - Inhab =	2.187359531
For community systems with CHP:				CO2 emission factor for heat =	0.1558
Electrical efficiency of CHP unit, 0.25 or:	0.19	Heat efficiency of CHP unit, 0.50 or:	0.5	Pollution emissions factor of heat =	0
CHP fuel - CO2 emission factor:	0.19	CHP fuel - pollution emission factor:	0.879	Gross CO2 emission =	62.34073823
Electricity CO2 emission factor:	0.59	Electricity - pollution emission factor:	6.494	Net CO2 emission =	60.8489574
Boiler - CO2 emission factor:	0.19	Boiler - pollution emission factor:	0.879	Gross Pollution Emissions - Inhab =	3.818430856
				Net Pollution Emissions - Inhab =	3.818430856

To be completed for all dwellings:					
Pumps and fans - CO2 emission factor:	0.59	Pollution emission factor:	6.494		
Lights and appliances - CO2 emission factor:	0.59	Pollution emission factor:	6.494		
Cooking - CO2 emission factor:	0.19	Pollution emission factor:	0.879		
Area of green space (m2):	165				
				Gross CO2 emission =	57.94163943
				Net CO2 emission =	52.83342767
				Gross Pollution Emissions - Inhab =	2.102452936
				Net Pollution Emissions - Inhab =	2.102452936
				CO2 Emmision: Inhabitation =	52.83342767
				Pollution Emissions - Inhab =	2.102452936

Lifespan and Replacement Ratios

For life expectancy of building components, refer to Table X

Lifespan benchmark (years):	60			
Roof external finish - Life span (years):	46	1.30	Replacement ratio =	2
Roof structure - Life span (years):	60	1.00	Replacement ratio =	1
Roof insulation - Life span (years):	60	1.00	Replacement ratio =	1
Roof internal finish - Life span (years):	73	0.82	Replacement ratio =	1
Wall external finish - Life span (years):	60	1.00	Replacement ratio =	1
Wall structure - Life span (years):	60	1.00	Replacement ratio =	1
Wall insulation - Life span (years):	60	1.00	Replacement ratio =	1
Wall internal finish - Life span (years):	60	1.00	Replacement ratio =	1
Window and rooflight - Life span (years):	32	1.88	Replacement ratio =	2
Floor finish - Life span (years):	52	1.15	Replacement ratio =	2
Floor structure - Life span (years):	60	1.00	Replacement ratio =	1
Floor insulation - Life span (years):	60	1.00	Replacement ratio =	1
Internal Staircases - Life span (years):	78	0.77	Replacement ratio =	1
Photovoltaic panels - Life span (years):	25	2.40	Replacement ratio =	3
Solar water panels - Life span (years):	25	2.40	Replacement ratio =	3

Embodied Energy

For densities of materials, refer to Table C

For embodied energy of materials, refer to Table C

Is dwelling a house - Yes=1, No=0:	1				
Is dwelling a flat or apartment - Yes=1, No=0:	0	If flat, total number of dwellings within building:	1		
Foundations					
If strip/trench footing - Yes=1, No=0:	1				
Are there internal foundations - Yes=1, No=0:	0	Length of internal foundations (m):	0		
Strip/trench depth (m):	0.2	Strip/trench width (m):	0.6	Volume =, or insert value (m3):	3.35
Strip/trench - Density (kg/m3):	2600	Strip/trench - Embodied energy (kWh/kg):	0.2		1742.21
Wall width below ground (combined if twin leaf):	0.2	Depth of wall below ground (m):	0.8	Volume =, or insert value (m3):	4.47
Wall - Density (kg/m3):	2600	Wall - Embodied energy (kWh/kg):	1.2		13937.66
Cavity width (m):	0.1	Depth of cavity fill (m):	0.8	Volume =, or insert value (m3):	2.23
Cavity fill - Density (kg/m3):	500	Cavity fill - Embodied energy (kWh/kg):	0.01		11.17
					15691.04
If pile foundation - Yes=1, No=0:	0				
Number of piles:		Cross-sectional area of pile (m2):			
Depth of piles (m):				Volume =, or insert value (m3):	0.00
Pile - Density (kg/m3):	2600	Pile - Embodied energy (kWh/kg):	0.2		0.00
Number of pile caps:		Cross-sectional area of pile caps (m2):			
Depth of pile caps (m):				Volume =, or insert value (m3):	0.00
Pile cap - Density (kg/m3):	2600	Pile cap - Embodied energy (kWh/kg):	0.2		0.00
Depth of ground beams (m):	0.6	Width of ground beams (m):	0.3		
Length of ground beams (m)				Volume =, or insert value (m3):	0.00
Ground beam - Density (kg/m3):	2600	Ground beam - Embodied energy (kWh/kg):	0.2		0.00
					0.00

If pad foundation - Yes=1, No=0:	0				
Number of pads:		Pad length (m):			
Pad width (m):		Pad depth (m)		Volume =, or insert value (m3):	0.00
Pad - Density (kg/m3):	2600	Pad - Embodied energy (kWh/kg):	0.2		0.00
Depth of ground beams (m):	0.6	Width of ground beams (m):	0.3		
Length of ground beams (m)				Volume =, or insert value (m3):	0.00
Ground beam - Density (kg/m3):	0	Ground beam - Embodied energy (kWh/kg):	0		0.00
					0.00
				Embodied Energy - Foundations =	15691.04
Basement					
Perimeter, as ground floor or other (m2):	0	Depth (m):	0		
Wall width (m):	0			Volume =, or insert value (m3):	0.00
Note: *Enter zero if accounted for in depth of strip foundation walls*					
Wall - Density (kg/m3):	0	Wall - Embodied energy (kWh/kg):	0		0.00
Tanking thickness (m)				Volume =, or insert value (m3):	0.00
Tanking - Density (kg/m3):	0	Tanking - Embodied energy (kWh/kg):	0		0.00
Wall insulation thickness (m):		Wall insulatiopn depth (m)		Volume =, or insert value (m3):	0.00
Wall insulation - Density (kg/m3):	0	Wall Insulation - Embodied energy (kWh/kg):	0		0.00
Area of floor, as ground floor or other (m2):	0	Depth of floor (m):	0	Volume =, or insert value (m3):	0.00
Floor - Density (kg/m3):	0	Floor - Embodied energy (kWh/kg):	0		0.00
Floor insulation depth (m):				Volume =, or insert value (m3):	0.00
Floor insulation - Density (kg/m3):	0	Floor insulation - Embodied energy (kWh/kg):	0		0.00
Hardcore depth (m):	0			Volume =, or insert value (m3):	0.00
Note: *Enter zero if to be accounted for in ground floor analysis*					
Hardcore - Density (kg/m3):	0	Hardcore - Embodied energy (kWh/kg):	0		0.00
				Embodied Energy - Basement =	0.00
Frame					
Number of columns:	0	Cross-sectional area of columns (m2):			
Column height (m):				Volume =, or insert value (m3):	0.00
Column - Density (kg/m3):	0	Column - Embodied energy (kWh/kg):	0		0.00
Number of beams per floor:		Cross-sectional area of beams (m2):			
Beam length (m):				Volume =, or insert value (m3):	0.00
Beam - Density (kg/m3):	0	Beam - Embodied energy (kWh/kg):	0		0.00
				Embodied Energy - Frame =	0.00
Ground Floor					
Is floor timber construction? Yes=1, No=0:	0	Is floor concrte slab? Yes=1, No=0:	1		
Is floor concrte beam/block? Yes=1, No=0:	0				
If timber:					
Floor dimension perpendicular to span (m):		Length of span (m):			
Number of joists = actual, or:	1	Number of noggins = actual, or:	0		
Area of noggin cross-section (m2):	0.0026			Volume =, or insert value (m3):	7.30
Timber - Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1		511.00
Insulation				Volume =, or insert value (m3):	1.46
Insulation - Density (kg/m3):	24	Insulation - Embodied energy (kWh/kg):	0.49		17.17
					528.17
If concrete slab:					
Screed				Volume =, or insert value (m3):	1.83
Screed - Density (kg/m3):	1500	Screed - Embodied energy (kWh/kg):	0.2		1095.00
Concrete				Volume =, or insert value (m3):	10.95
Concrete - Density (kg/m3):	2600	Concrete - Embodied energy (kWh/kg):	0.2		5694.00
Insulation				Volume =, or insert value (m3):	1.46
Insulation - Density (kg/m3):	25	Insulation - Embodied energy (kWh/kg):	3.9		142.35
Hardcore				Volume =, or insert value (m3):	10.95
Hardcore - Density (kg/m3):	500	Hardcore - Embodied energy (kWh/kg):	0.01		54.75
					6986.10
If concrete beam and block:					
Floor dimension perpendicular to span (m):		Length of span (m):			
Beam spacing (m):	0.6	Number of beams = actual, or:	1		
Area of beam cross-section (m2):	0.36	Length of block (mean) (m):	0.6		

Width of block (m):	0.3	Number of blocks = actual, or:	0.0		
Beams				Volume =, or insert value (m3):	0.00
Beam - Density (kg/m3):	2600	Beam - Embodied energy (kWh/kg):	0.2		0
Blocks				Volume =, or insert value (m3):	0
Block - Density (kg/m3):	800	Block - Embodied energy (kWh/kg):	1.2		0
Screed depth (m):	0.05			Volume =, or insert value (m3):	1.83
Screed - Density (kg/m3):	800	Screed - Embodied energy (kWh/kg):	0.6		876
Insulation				Volume =, or insert value (m3):	1.46
Insulation - Density (kg/m3):	25	Insulation - Embodied energy (kWh/kg):	0.49		17.885
					893.89
External Walls				Embodied Energy - Gnd Floor =	6986.10
External wall length (m):	19.9				
External Walls - Masonry					
External finish				Volume =, or insert value (m3):	0.00
External finish - Density (kg/m3):		External finish - Embodied energy (kWh/kg):			0.00
Outer leaf				Volume =, or insert value (m3):	8.28
Outer leaf - Density (kg/m3):	2600	Outer leaf - Embodied energy (kWh/kg):	1.2		25846.08
Insulation				Volume =, or insert value (m3):	3.31
Insulation - Density (kg/m3):	25	Insulation - Embodied energy (kWh/kg):	3.9		323.06
Inner leaf				Volume =, or insert value (m3):	8.28
Inner leaf - Density (kg/m3):	800	Inner leaf - Embodied energy (kWh/kg):	0.5		3313.60
Internal finish				Volume =, or insert value (m3):	0.99
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	1		596.45
				Embodied energy =	30079.20
External Walls - Timber Frame					
External finish				Volume =, or insert value (m3):	0.00
External finish - Density (kg/m3):	0	External finish - Embodied energy (kWh/kg):	1		0.00
Outer leaf				Volume =, or insert value (m3):	8.28
Outer leaf - Density (kg/m3):	700	Outer leaf - Embodied energy (kWh/kg):	0.1		579.88
Sheathing ply				Volume =, or insert value (m3):	0.00
Sheathing ply - Density (kg/m3):	700	Sheathing ply - Embodied energy (kWh/kg):	0.1		0.00
Insulation				Volume =, or insert value (m3):	3.04
Insulation - Density (kg/m3):	40	Insulation - Embodied energy (kWh/kg):	0.49		59.53
Stud width (m):	0.05	Stud depth (m):	0.1		
Sole plate width (m):	0.1	Sole plate depth (m):	0.05		
Head plate width (m):	0.1	Head plate depth (m):	0.05		
Header Joist width (m):	0.1	Hearder Joist depth (m):	0.25		
Inner leaf				Volume =, or insert value (m3):	3.24
Inner leaf - Density (kg/m3):	700	Inner leaf - Embodied energy (kWh/kg):	0.1		226.95
Internal finish				Volume =, or insert value (m3):	0.99
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5		298.224
				Embodied energy =	1164.59
Party Walls - Masonry					
Insulation - Thickness (m):	0			Volume =, or insert value (m3):	0.00
Insulation - Density (kg/m3):	25	Insulation - Embodied energy (kWh/kg):	3.9		0.00
Inner leaf - Thickness (m):	0.1			Volume =, or insert value (m3):	4.01
Inner leaf - Density (kg/m3):	800	Inner leaf - Embodied energy (kWh/kg):	0.5		1604
Internal finish - Thickness (m):	0.012			Volume =, or insert value (m3):	0.4812
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	1		288.72
				Embodied energy =	1892.72
Party Walls - Timber Frame					
Sheathing ply				Volume =, or insert value (m3):	0
Sheathing ply - Density (kg/m3):	700	Sheathing ply - Embodied energy (kWh/kg):	0.1		0
Insulation - Thickness (m):				Volume =, or insert value (m3):	0
Insulation - Density (kg/m3):	40	Insulation - Embodied energy (kWh/kg):	0.49		0
Stud width (m):	0.05	Stud depth (m):	0.1		
Sole plate width (m):	0.1	Sole plate depth (m):	0.05		
Head plate width (m):	0.1	Head plate depth (m):	0.05		
Header Joist width (m):	0.1	Hearder Joist depth (m):	0.25		

Inner leaf - Thickness (m):	0.1			Volume =, or insert value (m3):	1.30
Inner leaf - Density (kg/m3):	700	Inner leaf - Embodied energy (kWh/kg):	0.1		90.75966667
Internal finish - Thickness (m):	0.012			Volume =, or insert value (m3):	0.4812
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5		144.36
				Embodied energy =	235.12
Internal Load Bearing Walls					
Length of internal loadbearing walls (m):	0	Height of internal loadbearing walls (m):	6		
Masonry					
Structure - Thickness (m):	0.1			Volume =, or insert value (m3):	0.00
Structure - Density (kg.m-3):	1200	Structure - Embodied Energy (kWh/kg):	0.5		0
Finish - Thickness (m):	0.012			Volume =, or insert value (m3):	0.00
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	1		0
				Embodied Energy =	0.00
Timber Frame				Volume =, or insert value (m3):	0.00
Sheathing ply					0
Sheathing ply - Density (kg/m3):	700	Sheathing ply - Embodied energy (kWh/kg):	0.1		
Stud width (m):	0.05	Stud depth (m):	0.1		
Sole plate width (m):	0.1	Sole plate depth (m):	0.05		
Head plate width (m):	0.1	Head plate depth (m):	0.05		
Header Joist width (m):	0.1	Hearder Joist depth (m):	0.25		
Structure - Thickness (m):	0.1			Volume =, or insert value (m3):	0.00
Inner leaf - Density (kg/m3):	700	Inner leaf - Density (kg/m3):	0.1		0
Internal finish - Thickness (m):	0.012			Volume =, or insert value (m3):	0
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5		0
				Embodied energy =	0.00
				Embodied Energy - Walls =	31971.924
Windows and Rooflights					
Level of glazing:	2	Pane tickness (m):	0.005	Volume =, or insert value (m3):	0.1282
Glass - Density (kg/m3):	2500	Glass - Embodied energy (kWh/kg):	6		3846
Perimeter of windows and rooflights, inc midrails (m):	28.68	Area of frame cross section (m2):	0.0002	Volume =, or insert value (m3):	0.005736
Frame - Density (kg/m3):	1050	Frame - Embodied energy (kWh/kg):	14.7		177.07032
				Embodied Energy - Glazing =	4023.07032
Internal Floors					
Are floors timber construction? Yes=1, No=0:	1	Are floors concrte beam/block? Yes=1, No=0:	0		
If timber:					
First floor - dimension perpendicular to span (m):	8.025	First floor - length of span (m):	5.025		
Joist spacing (m):	0.6	Number of joists = actual, or:	15		
Joist depth (m):	0.26	Joist width (m):	0.05		
Area of noggin cross-section (m2):	0.0026	Number of noggins = actual, or:	2		
Floorboard thickness (m):	0.019	Total area of internal floors (m2):	36.5	Volume =, or insert value (m3):	1.715105
Timber Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1		120.05735
Soffit finish thickness (m)	0.015			Volume =, or insert value (m3):	0.5475
Soffit finish - Density (kg/m3):	600	Soffit finish - Embodied energy (kWh/kg):	0.5		164.25
				Embodied energy =	284.30735
If concrete beam and block:					
First floor - dimension perpendicular to span (m):	8.025	First floor - length of span (m):	5.025		
Beam spacing (m):	0.9	Number of beams = actual, or:	10		
Area of beam cross-section (m2):	0.36	Length of block (mean) (m):	0.9		
Width of block (m):	0.3	Number of blocks = actual, or:	150.75	Volume =, or insert value (m3):	18.09
Beam - Density (kg/m3):	1200	Beam - Embodied energy (kWh/kg):	600		13024800
				Volume =, or insert value (m3):	48.843
Block - Density (kg/m3):	800	Block - Embodied energy (kWh/kg):	600		23444640
Screed depth (m):	0.05			Volume =, or insert value (m3):	1.825
Screed - Density (kg/m3):	800	Screed - Embodied energy (kWh/kg):	0.6		876
Soffit finish thickness (m)	0.015			Volume =, or insert value (m3):	0.5475
Soffit finish - Density (kg/m3):	600	Soffit finish - Embodied energy (kWh/kg):	0.5		164.25
				Embodied Energy =	36470480.25

Total area of internal floors (m2):	36.5				
Internal Staircases				Embodied Energy - Int'l Floors =	284.30735
Are stairs other than precast concrete? Yes=1, No=0	1	Are internal stairs precast concrete? Yes=1, No=0	0		
Number of flights	1				
For stairs other than precast concrete					
Number of treads	13	Number of risers	14		
Tread length (m):	0.21	Tread width (m):	0.95		
Tread thickness (m):	0.025				
Tread - Density (kg/m3):	700	Tread - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0.0648375
Riser height (m):	0.19	Riser width (m):	0.95		4.538625
Riser thickness (m):	0.025				
Riser - Density (kg/m3):	700	Riser - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0.063175
Staircase length (m):	3.8				4.42225
String depth (m):	0.25	String thickness (m):	0.035		
String - Density (kg/m3):	700	String - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	0.0665
					4.655
Precast concrete stairs				Embodied energy =	13.615875
Staircase length (m):		Staircase width (m):			
Mean staicase slab thckness (m):					
Staircase - Density (kg/m3):		Staircase - Embodied energy (kWh/kg):		Volume =, or insert value (m3):	0
					0
				Embodied energy =	0
Roof				Embodied Energy - Int'l Stairs =	13.615875
Area of roof (excluding openings) (m2):	48.6	Area, parallel to ceiling plane (m2):	36.5		
Roof length (m):	8.025				
Area per unit of outer finsih (tile or sheet) (m2):	0.09	Area of overlap of outer finish (m2/unit):	0.009		
Outer finish - Density (kg/m3):	700	Outer finish - Embodied energy (kWh/kg):	0.27	Volume =, or insert value (m3):	2.673
Waterproof Layer - Density (kg/m3):	400	Waterproof Layer - Embodied energy (kWh/kg):	4.5		1010.394
Is structure timber? Yes=1, No=0:	1	Is structure steel? Yes=1, No=0:	0		437.4
If timber:					
Volume per truss or joist and firring (m3):	0.15	Number of trusses or joists, actual or:	15		
Volume per batten (m3):	0.006	Number of battens:	28		
Timber Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	2.418
If steel:					169.26
Area of beam cross-section (m2):					
Beam spacing (m):		Beam length (m):			
Beam - Density (kg/m3):	7900	Number of beams = actual, or:	0	Volume =, or insert value (m3):	0
		Beam - Embodied energy (kWh/kg):	10		0
Insulation					
Insulation - Density (kg/m3):	24	Insulation - Embodied energy (kWh/kg):	3.9	Volume =, or insert value (m3):	6.691666667
Internal finish					626.34
Is internal finish in horizontal plane? Yes=1, No=0:	1	Is internal finish parallel to pitch? Yes=1, No=0:	0	Volume =, or insert value (m3):	0.438
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh.kg-1):	0.5		131.4
				Embodied Energy - Roof =	2374.794
					840.3404321
Anticipated percentage of construction waste (%):	10	Typical practice = 10, Best practice = 2.5			840.3404321
				Embodied Energy - Dwelling =	840.3404321
Photovoltaic panels - Embodied energy (kWh.m-2)				Embodied Energy - Photovoltaics =	0
Solar water panels - Embodied energy (kWh.m-2)				Embodied Energy - Solar water heating =	0
Embodied CO2				Ecological Weight - Em Energy =	924.3744753
Percentage of fuel that is Electricity (%):	33.33	Emission Factor (kgCO2.kWh-1):	0.59		181.7754675
Percentage of fuel that is Gas (%):	33.33	Emission Factor (kgCO2.kWh-1):	0.19		58.5378624
Percentage of fuel that is Petroleum (%):	33.33	Emission Factor (kgCO2.kWh-1):	0.27		83.18538341
Percentage of fuel that is Coal (%):		Emission Factor (kgCO2.kWh-1):	0.31		0

Ecological Weight - Em CO2 =	323.4987133

Other Greenhouse Gas Emissions

HCFC content of Insulation (kgHCFC.m-3) (Table Y):	0
	0
Other G'house Gas Emissions =	0.00

Benchmark Performance

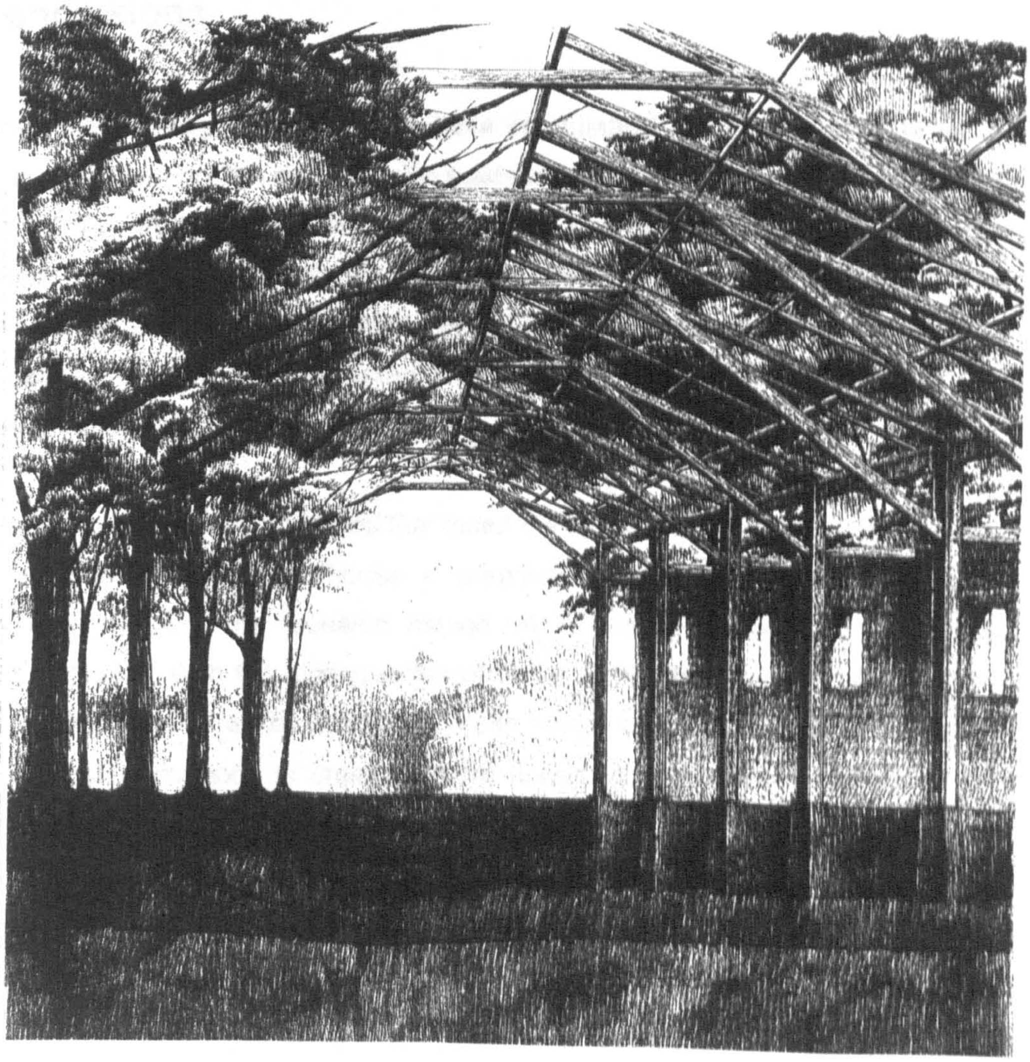
Energy Consumption: Inhab =	199.6
Energy Generation: Inhab =	0
Ventilation =	0.67
Airtightness =	13
Ecological Wght: Embodied Energy =	924.4
CO2 Emissions: Inhab =	52.83
Lifespan =	60
Pollution: Energy Con Inhab =	2.1025
Thermal Performance: U-roof =	0.25
Thermal Performance: U-wall =	0.43
Thermal Performance: U-floor =	0.43
Thermal Performance: U-window =	3.3
Thermal Performance: U-door =	3.3
Ecological Wght: Embodied CO2 =	323.5
Other Greenhouse Gas Emissions =	0.00
Water Consumption: Total =	160.0
Water Consumption: Potable =	160.0

Scoring

Energy Consumption: Inhab =	0.22343515
Energy Generation: Inhab =	0.00
Ventilation =	0.108044348
Airtightness =	0.002079231
Ecological Weight: Embodied Energy =	0.082758668
CO2 Emissions: Inhab =	0.053871197
Lifespan =	0.063
Pollution: Energy Con Inhab =	0.046321132
Thermal Performance: U-roof =	0.004585917
Thermal Performance: U-wall =	0.006897149
Thermal Performance: U-floor =	0.003232764
Thermal Performance: U-window =	0.000917781
Thermal Performance: U-door =	0.000112754
Ecological Weight: Embodied CO2 =	0.010293704
Other Greenhouse Gas Emissions =	0.034
Water Consumption: Total =	0.00418
Water Consumption: Potable =	0.00085

Score =	17.93

Chapter 12



Conclusions

12.0 Conclusions

The previous eleven stages of the thesis have established the key issues that faced the work, a reflection on the ecologically sustainable ideal dwelling, and evaluated current knowledge in the field; the holistic criteria and benchmarks that define the 'urban house in paradise' were then developed. Both a hierarchy and interrelated links between the criteria were created, establishing the structure upon which to devise an assessment tool that evaluates dwellings against the benchmarks; this was subsequently validated.

Having considered the key holistic issues that faced the thesis and established the principal terms of reference for the 'urban house in paradise', a reflection on the ecologically sustainable ideal dwelling, the research moved on to evaluate existing environmental assessment methods. With the inadequacies of these highlighted, the next stage of the research identified the criteria that define the 'urban house in paradise', criteria that widen the scope of existing methods to create a more holistic and effective evaluation of the dwelling. Benchmark values were then established for these criteria, which constitute the way in which the standard of performance of the 'urban house in paradise' is quantitatively defined and communicated. These benchmarks were set against case studies of dwellings that embody best practice in a northern European context, to demonstrate that the theoretical values proposed can be achieved in reality and are not beyond the realm of technical feasibility.

Two of the principal inadequacies of existing assessment methods that were identified are the lack of hierarchy and the interrelation between the criteria used in the assessment. The next chapter established a rating of significance for the criteria, based on their relative contribution to increasing the ecological sustainability of the dwelling. The thesis then identified and quantified interrelated linkages between the criteria, to create a structure upon which to devise a methodology to assess a dwelling against the benchmarks of the 'urban house in paradise' at the design stage. The assessment tool was then validated against the final drawn studies, against literature review, and by critical interviews with relevant specialists.

12.1 Conclusions on Criteria

The appraisal of existing assessment methods identified some inadequacies, in particular a lack of interrelation between criteria, that longevity of both dwelling and materials is infrequently and indirectly considered, and that assessments are predominantly anthropocentric. The criteria that define the 'urban house in paradise' were then identified, increasing the range considered in existing assessments to create a more holistic and effective evaluation of the dwelling.

Defining the holistic performance of a dwelling through a set of criteria has been demonstrated as a provable concept. Further, the importance of a holistic attitude in defining that performance has also been established. The latter point is exemplified in the relationship between the Ecological Weight: Embodied Energy, Energy Consumption: Inhabitation and the Thermal Mass benchmarks. An isolated approach to reducing the embodied energy of the dwelling may adversely affect its thermal mass and therefore its energy consumption and comfort during inhabitation; thus a balance needs to be established between these three criteria. Whilst they are intended to be holistic, should it emerge that additional criteria are required, they can be integrated into the set of criteria proposed. This is demonstrated by the suggested inclusion of a benchmark of thermal mass below.

The criteria define the holistic, objective performance of the dwelling. They are not intended to impinge or inhibit the creative process, proffering a monistic approach to the design of the 'urban house in paradise'; rather they are generic and could be realised in many forms. To enable an assessment of the architectural quality of the dwelling, a series of subjective criteria have been proposed that could form a parallel assessment. During the thesis these were not integrated into the criteria that define the 'urban house in paradise' for a number of reasons. Firstly, it was considered that to develop a robust assessment methodology for both objective and subjective criteria was beyond the scope of this thesis. Secondly, including criteria that benchmark subjective design quality could impinge upon the freedom of the creative process, and might orientate that process toward the criteria being assessed, at the expense of responding to other influences that might drive a creative response. Thirdly, it would require consensus on what constitutes high quality design, which might prove difficult to achieve in a sufficiently robust manner. Fourthly, the assessment methodology of the 'urban house in paradise' is intended to be a design tool that can be used internally within an office to enable a designer to identify the most ecologically sustainable performance of a particular design, and to refine that performance throughout the design process. An assessment of subjective design quality would be difficult to achieve internally and would more likely be based on an external peer review, compromising this intention.

12.2 Conclusions on Benchmarks

Creating performance benchmarks for the criteria to quantitatively define the performance of the 'urban house in paradise' based on technical feasibility yet innovating upon best practice in a northern European context has, in terms of the values proposed, largely been demonstrated as a provable concept.

The thesis has proved that the most significant contribution which can be made to improving the environmental sustainability of the dwelling is to reduce energy consumption during the period of inhabitation; its rating in the hierarchy of the criteria is three times more than that of the second most significant, energy generation during inhabitation.[1] Also proven is that, in terms of achieving the benchmarked reduction in energy consumption, minimising unwanted air infiltration through increasing the air tightness of the envelope will create the greatest singular increase in the environmental sustainability of the dwelling; significantly more so, by a factor of almost three, than increasing the thermal performance of the fabric. This latter point is a radical departure from the common perception held by many people of how to reduce energy consumption in dwellings.

Analysis of ecological footprints has identified that to fulfil global demands for natural resources and to assimilate emissions would require the equivalent land area of three planet earths.[2] An alternative would be to substantially reduce consumption and emissions. Adopting an incremental approach to benchmarking, improving targets year on year, would be one way in which to achieve a Factor Four reduction in resource use over and above the growth in housing numbers that has been identified. This would demand a cut in resource consumption of 75 percent from current levels today, rising to 94 percent of current levels by 2021. The proposed initial reduction to one quarter of the current level of resource consumption is, on average, achieved by the proposed benchmarks of the 'urban house in

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[1] When environmental sustainability was considered as reduction in contribution to global warming, reduction in pollution emissions, reduction in natural resource consumption including habitat destruction, and reduction in ozone depleting emissions.

paradise', and has been proven as technically feasible through the benchmarking and the drawn studies.

12.3 Potential Revisions to the Proposed Benchmark Values

Through both the analysis of the drawn studies and the suggested inclusion of a benchmark for thermal mass, it is suggested that the Ecological Weight: Embodied Energy and Embodied CO_2 benchmarks are increased. Achieving others, such as Energy Consumption: Inhabitation will be dependent on behavioural patterns of the inhabitants. This, in conjunction with other elements of the research, suggests potential revisions to some of the benchmark values of the criteria that define the 'urban house in paradise'. Some benchmarks could be construed as influencing the design process.

12.3.1 Ecological Significance of the Site

Despite an extensive literature review, at the time the benchmarks were quantified and the subsequent prioritising undertaken, data could not be determined to relate the area of a plot of land to the number of species of wildlife that might be expected to inhabit it. This clearly would have an impact on the ecological value of the site, and would be an additional way in which to differentiate between low and high ecological value, beyond whether it is greenfield or brownfield, when selecting a site. However, in August 2000 the Department of the Environment, Transport and the Regions (DETR) published such data,[3] following research undertaken as a requirement of the UN Convention on Biological Biodiversity to monitor botanical biodiversity and identify activities likely to have significant adverse impact on the conservation and sustainable use of it. This has culminated in a range of indicators of botanical diversity.

The research was based on the analysis of species diversity for a range of 1 km square grids; a new classification of vegetation was developed, termed the Countryside Vegetation System. This is broken down into eight major aggregate classes of species: crops, tall grassland, fertile grassland, infertile grassland, lowland wooded, upland wooded, moorland grass and heath. The mean number of species per plot type was then derived. It would be

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[2] Wackernagel, M. and W. Rees. *Our Ecological Footprint: Reducing Human Impact on the Earth*, Canada: New Society Publishers, 1995.

possible to utilise this data to determine the likely ecological value of a site in species terms for given land types, and therefore to quantify a benchmark for using a site of low ecological value.

12.3.2 Ecological Weight: Embodied Energy and Embodied CO_2

The validation through Drawn Study Seven suggested that the benchmarks for Ecological Weight: Embodied Energy and Embodied CO_2 might be increased to be more achievable; even using the very low embodied energy technology of timber frame construction, the Drawn Study struggled to achieve them. The impact of using other construction methods to create the walls of the dwelling was studied; each one increased the embodied energy over its benchmark. There are a number of precedents that demonstrate that timber frame dwellings can achieve very high performance standards, whilst using a renewable resource with relatively low embodied energy; this might suggest a direction in house building that the Ecological Weight: Embodied Energy benchmark could be used to initiate. However, it could also be considered that the benchmark of 250 $kWh.m^{-2}$ impinges upon the creative design of the dwelling, in terms of its materiality, and therefore is inappropriate to urban sites; this is discussed further in 12.8, Conclusion on Drawn Studies, below.

Increasing the benchmark would also allow more thermally massive approaches to be adopted which, according to Vale and Vale, is important in low energy design,[4] and for the comfort of the inhabitants of dwellings that make use of passive solar gain. This is also borne out in the specialist interviews. During Validation and Testing it was established that the mid- and high-mass variants of the drawn study would have an Ecological Weight: Embodied Energy benchmarks of 369.6 $kWh.m^{-2}$ and 576.7 $kWh.m^{-2}$ respectively. Therefore if, as suggested below, the thermal mass benchmark is based upon interpolating between these two, an appropriate benchmark value can be determined as 500 $kWh.m^{-2}$. The corresponding Embodied CO_2 benchmark would be 180 $kgCO_2.m^{-2}$.[5]

The difficulty in achieving a balance between the Ecological Weight benchmarks and thermal mass is also demonstrated by Drawn Studies Four and Five, in which a specific

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[3] DETR website, 23 August 2000: www.wildlife-countryside.detr.gov.uk/vbc/ecofact2/index.htm

[4] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames and Hudson limited, 2000.

[5] The methodology used to determine the embodied CO_2 benchmark on the basis of embodied energy is contained within the benchmark analysis of the Ecological Weight: Embodied CO_2, refer to Annexe 3.14.

intention was to increase thermal mass. Using concrete throughout the dwelling, as blocks within the external and party walls and as a slab ground floor and beam and block upper floor, resulted in an embodied energy value of 640.6 $kWh.m^{-2}$. However, the level of thermal mass provided by this fabric may be above the quantity that would usefully contribute to the performance of the dwelling. This emphasises the need to establish a benchmark for thermal mass, and incorporate it into the calculation of Ecological Weight and Energy Consumption: Inhabitation benchmarks.

If the Ecological Weight: Embodied Energy benchmark were doubled to 500 $kWh.m^{-2}$, which is half that of the typical dwelling, provided that the design life expectancy of the dwelling achieves the benchmark of 120 years this will still represent a factor four reduction in the embodied energy, and therefore resource use, of the dwelling when considered over its life span. Although in relative terms the criterion of Energy Consumption: Inhabitation is over 5 times as significant in reducing the ecological impact of the dwelling than Ecological Weight: Embodied Energy, the latter should not be considered irrelevant or unimportant. If the energy consumption of the dwelling during inhabitation continues to be reduced, through improved air tightness, thermal insulation standards and responsible lifestyle decisions, the energy embodied within the dwelling will become increasingly significant. Therefore a balance needs to be struck between thermal mass, embodied energy and energy consumed during inhabitation. As has been maintained throughout the thesis, sustainability requires a holistic, interconnected approach.

12.3.3 Energy Consumption: Inhabitation

Drawn studies Seven and Eight show that the benchmark for Energy Consumption: Inhabitation, although achievable, would make behavioural demands on the lifestyle of the inhabitants of the dwelling; examples of this are the values of consumption through lighting, appliances and cooking. The values used in the energy calculation, 7.9 and 2.4 $kWh.m^{-2}.a^{-1}$, are based on the performance achieved through appliance selection and prudent use by the inhabitants.[6] If these were replaced by the typical consumption values for a three bedroom semi-detached dwelling, of 36 and 8 $kWh.m^{-2}.a^{-1}$ respectively, the Energy Consumption: Inhabitation benchmark would be increased from 24.26 to 57.89 $kWh.m^{-2}.a^{-1}$, more than doubling it.

Whether or not the benchmark should make demands of the inhabitants themselves relates, like transportation as discussed in the Introduction, to the tangential issue of lifestyle behaviour. Both of these factors demand that the inhabitants make conscious decisions, such as purchasing a low energy fridge, using low energy light fittings or commuting by train as opposed to car, to reduce ecological impact. The fact that not making these decisions relating to lighting, appliances and cooking could more than double the annual energy consumption of the dwelling during inhabitation implies that finding mechanisms to increase the awareness of inhabitants and encouraging them to adopt more sustainable behavioural patterns is a significant priority. To demonstrate this, the difference in energy consumption given above for the two behavioural scenarios is 33.72 $kWh.m^{-2}.a^{-1}$; across the 120 year design life span, this equates to 4,046.4 $kWh.m^{-2}$. This is over 16 times the Ecological Weight: Embodied Energy benchmark at 250 $kWh.m^{-2}$, or 8 times it at 500 $kWh.m^{-2}$, demonstrating that the Energy Consumption: Inhabitation benchmark, even at these low levels, still demands most attention, and that decisions made by the inhabitants of the dwelling could outweigh, in terms of ecological impact, some of the best intentions of the designer when considering the embodied energy of the dwelling. If proposing a benchmark that depends on behavioural patterns, and disseminating it in the correct manner such as identifying any financial as well as ecological benefit, could potentially influence such behaviour then it is more than justified. The value proposed is not regulatory, and therefore does not dictate these patterns, but is a guide to what is achievable, and demonstrates the significance and value of, and what is necessary for, achieving it. If voluntary measures proved insufficient, regulatory improvements for manufacturers in the efficiency of appliances would achieve the same result over time.

As discussed in the Introduction, the dwelling, through providing the foundation for a lifestyle, is an integral part of a wider picture, and should form an integrated part of a move toward more sustainable lifestyles. Otherwise these could, through ecologically irresponsible behaviour, outweigh the reductions in impacts upon the natural environment created by the dwelling.

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[6] These values are derived from the most efficient dwelling proposed in BRECSU. 'Building a Sustainable Future – Homes for an Autonomous Community', *General Information Report Number 53*, London: HMSO, October 1998.

12.3.4 Space Standards: Area

During Drawn Study Seven, of the dwelling for Ancotes, it emerged that the additional circulation required for a three-storey dwelling might adversely affect the minimum area for inhabitable spaces intended by the benchmark, as the space standards analysis were based upon flats and two-storey houses. Therefore the benchmark could be amended to incorporate a variation of 5 percent to account for the additional circulation space required for each additional storey.

12.3.5 Thermal Performance

Drawn Study Seven required that the thermal performance be increased above its benchmark in order to achieve that of Energy Consumption: Inhabitation. Whilst this has an impact upon the Ecological Weight: Embodied Energy benchmark, it does not imply that either value should necessarily be changed. It is feasible that for a different dwelling type, such as a flat which has fewer exposed elements, the Energy Consumption: Inhabitation benchmark could be achieved with the values proposed for the Thermal Performance benchmark. Furthermore, Energy Consumption: Inhabitation has a significance rating above that of either Thermal Performance of Ecological Weight: Embodied Energy and therefore is the principal target; this demonstrates the value in weighting the assessment, as it determines which benchmarks should be achieved at the expense of others to create the most ecologically sustainable solution.

12.3.6 Water Consumption: Inhabitation

The validation of Drawn Study Seven demonstrated that a dwelling would struggle to achieve the benchmarked water consumption from rainwater collection from its roof. However, in itself this does not constitute sufficient reason to increase the mains water consumption benchmark; as it stands it will provide an incentive for innovating in the collection and supply of other sources of rain and grey water to achieve the benchmark.

12.4 Potential Additional Criteria not Benchmark Valued

During the research, criteria have emerged that were not included within the initial benchmarking process. The validation by both drawn studies and specialist interviews suggested the addition of a thermal mass benchmark to the criteria that

define the 'urban house in paradise'. A benchmark is proposed on the basis of the drawn study and comparative values; however, it is recognised that this should be refined to establish a balance between the dependent criteria of Ecological Weight: Embodied Energy and Energy Consumption: Inhabitation. The acoustic performance of the fabric of the dwelling is another potential additional criterion.

Although not a performance criteria *per se*, as the thermal mass of a dwelling will contribute to its performance in terms of energy consumption; both the final drawn studies and specialist interviews have suggested the inclusion of a thermal mass benchmark.[7] Furthermore, it is proposed that an assessment against that proposed benchmark be integrated into the energy consumption prediction.

A theoretical upper limit for thermal mass is proposed by Lund for a super-insulated dwelling in Scandinavian latitudes, through suggesting that 100 m^3 of concrete would be required to achieve a zero space heating demand.[8] In a dwelling the size of a typical three bedroom semi-detached house, this would equate to a thermal mass of 0.583 $kWh.K^{-1}.m^{-2}$. It is worthy of note that the embodied energy of this concrete alone would be 494 $kWh.m^{-2}$; this is double the Ecological Weight: Embodied Energy benchmark of the 'urban house in paradise', and half the total embodied energy for a three bedroom semi-detached dwelling, as determined by the literature review. The earth-sheltered houses in Hockerton, Nottinghamshire, a terrace of five autonomous dwellings designed by Brenda and Robert Vale, are a constructed example of an upper limit for the benchmark. They were designed with the specific intention of maximising the thermal mass, achieving a level beyond that from the material required for structural purposes. The total mass of the dwelling is 2,278 $kg.m^{-2}$, or 0.639 $kWh.K^{-1}.m^{-2}$; this is in excess of the value proposed by Lund.[9]

It should be borne in mind that increasing the thermal mass has a directly proportional effect on increasing the embodied energy of the dwelling; therefore proposing an excessively high value, which is above that which provides a useful contribution to thermal storage, would have a detrimental effect on the overall sustainability of the dwelling. Therefore an additional element of further research, once the relationship between thermal mass, embodied energy and energy consumed during inhabitation have been determined, would

[7] As identified in the Analysis and Validation, refer to chapter 11.

[8] Lund, P. 'Optimum Solar House: Interplay Between Solar Aperture and Energy Storage', *International Solar Energy Society World Conference*, Helsinki: University of Technology, 1993; in Vale, Brenda and Robert. Op. Cit.

be to calculate the optimum balance between thermal mass and embodied energy, and therefore establish the optimum thermal mass benchmark. A preliminary proposal for the thermal mass benchmark, based upon interpolating between the mid- and high-mass variants of Drawn Study Seven, is given below. The thermal mass of a typical three bedroom semi-detached dwelling, the Hockerton dwelling and the Vale's dwelling in Southwell[10] are also included as comparative values.[11] The value is based upon the mass achieved with an Ecological Weight: Embodied Energy benchmark of 500 $kWh.m^{-2}$, and is over four times the mass of a typical three bedroom semi-detached dwelling. The benchmark is not increased above that of the Southwell dwelling, as beyond this value the mass would be in excess of that required for structural purposes; until it is proven that the benefit of this mass outweighs the additional material and embodied energy consumption, this is considered an inefficient use of material.

Dwelling	Thermal mass ($kWh.K^{-1}.m^{-2}$)
Typical three bedroom semi-detached	0.042
Vale house, Southwell	0.218
Hockerton house	0.639
'urban house in paradise'	0.018

Table 17: Benchmark values of thermal mass

The dual party walls in Drawn Studies 5 and 8 were intended to minimise noise transmission between dwellings. In an urban environment minimising the transmission of noise from outside to the interior of the dwelling is also an important consideration. Therefore, in addition to providing a thermal performance benchmark for the fabric of the dwelling, an acoustic one could also be developed; this would apply to separating partitions within a block or terrace which the thermal performance does not. The Building Regulations provide standard values for the typical performance of a variety of construction technologies,[12] however these are to be revised shortly.[13]

[9] Brenda and Robert. Op. Cit.
[10] This dwelling was appraised in the second case study, refer to 5.2.
[11] The 'urban house in paradise' benchmark could be refined in line with the suggested methodology using the assessment tool.
[12] Department of the Environment and the Welsh Office. *The Building Regulations – Approved Document E: Resistance to the Passage of Sound*, London: HMSO, 1992.
[13] Pearson, Andy. 'Noisy Neighbour Rules Spell Trouble for House Builders', *Building*, 27 October 2000.

For masonry elements it would be feasible to use the existing methodology of the tool to assess the acoustic performance of the fabric. The Building Regulations assess the acoustic performance of masonry walls and floors in terms of mass per unit area, $kg.m^{-2}$. The steps to determine the embodied energy of the dwelling, in addition to being revised to determine the thermal mass, could also be developed to calculate the acoustic mass of the structure. The Building Regulations provide values for the performance of technologies used to construct the majority of dwellings, and therefore provide a 'typical' performance benchmark, of 415 $kg.m^{-2}$ for party and external walls and 365 $kg.m^{-2}$ for intermediate floors. However, the scope of the research has not enabled a benchmark analysis of a proposed value for the 'urban house in paradise'; this would require further research to determine the optimal level of mass required to minimise sound transmission, informed by comparative examples of best practice.

12.5 Conclusions on Prioritisation of Criteria

Subsequent to the prioritising of the criteria, research was published on the perceived relative significance between different parameters of ecological degradation. These weightings were integrated into the hierarchy determined in chapter 7.0 to determine the impact on the most significant criteria; relatively little change was made. Through prioritising, the research has established the most significant ways in which to increase the ecological sustainability of the dwelling; this could be used to target improvements in the house building industry.

At the time that the prioritising of the criteria was undertaken, no relative significance between the parameters of environmental degradation was determined. Therefore the reduction in greenhouse gas emissions, pollution, natural resource consumption including habitat destruction, and ozone depleting emissions were all considered equal in contributing to improving the ecological sustainability of the dwelling. In calculating the overall priority, the normalised ratio for each of the criteria was directly added across the four parameters of environmental degradation to determine the overall weighting.

In May 2000, the Building Research Establishment published a study it had undertaken in the development of Ecopoints, a method of sustainability measurement.[14] During their research a study was undertaken to identify the relative importance of different issues of sustainability. Following extensive literature review the researchers developed a list of parameters of sustainability, encompassing ecological, economic and social issues. A series of focus groups were then used to attribute weightings to each of the parameters; these were intended to encompass members of the construction industry's main stakeholders.[15] The weightings are expressed as a percentage, and so all total one hundred. The most significant of the ecological parameters in terms of their overall weightings were: climate change, ozone depletion, toxic air pollution, acid deposition, fossil fuel depletion and habitat and ecosystem destruction; these bear close comparability to the parameters used by the thesis, identified above, to weight the criteria of the 'urban house in paradise', which gives confidence in the analysis used within the thesis.

However, in the knowledge of this data, it was possible to take the prioritising of the criteria a stage further. The weightings that have been identified in the Building Research Establishment's study were applied to the prioritising process for the four parameters of ecological degradation used by the thesis. This determines how the weighted significance of different forms of ecological degradation affects the overall hierarchy of the criteria. The process multiplies the weightings identified by the Building Research Establishment by the normalised ratios identified for each of the criteria under each parameter of ecological degradation. This is demonstrated in the Table 18 overleaf.

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[14] 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.

[15] The focus groups were: Government policy makers and researchers, construction professionals, construction material producers and manufacturers, property and institutional investors, environmental activists and lobbyists, local authority policy makers and planners, and academics and researchers.

Criteria	Normalised Ratio								
	GLOBAL WARMING		POLLUTION		NATURAL RESOURCES		OZONE DEPLETION		TOTAL
	Ratio	x Weighting (8.4)	Ratio	x Weighting (4.2)	Ratio	x Weighting (9.4)	Ratio	x Weighting (1.8)	
Carbon Intensity	0.016	0.134	Counted elsewhere		0.0	0.000	0.0	0.000	0.134
CO2 Em: Con/Decon	0.004	0.034	0.0	0.000	0.0	0.000	0.0	0.000	0.034
CO2 Em: Inhabitation	0.266	2.234	0.0	0.000	0.0	0.000	0.0	0.000	2.234
Construction Period	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Contextual Sig Site	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Decon/Demol: Recycling	0.0002	0.002	0.000	0.000	0.022	0.207	0.000	0.000	0.208
Design Life Span	0.008	0.067	0.034	0.143	0.005	0.047	0.079	0.142	0.399
Density: Quantitative	0.016	0.134	0.000	0.000	0.001	0.007	0.0	0.000	0.141
Density: Qualitative	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Diversity	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Domestic Waste: Recyling	0.025	0.210	0.0	0.000	0.0004	0.004	0.0	0.000	0.214
Eco Sig of Site	0.008	0.067	0.0	0.000	0.0002	0.002	0.0	0.000	0.069
Eco Weight: Em Energy	0.039	0.328	0.078	0.328	0.012	0.113	0.177	0.319	1.087
Eco Weight: Em CO2	0.037	0.311	0.000	0.000	0.0	0.000	0.0	0.000	0.311
Energy Con: Construction Process	0.005	0.042	0.009	0.038	0.001	0.009	0.015	0.027	0.116
Energy Con: Inhabitation	0.316	2.654	0.465	1.953	0.610	5.734	0.393	0.707	11.049
Energy Gen Inhabitation	0.110	0.924	0.220	0.924	0.092	0.865	0.117	0.211	2.923
Green Space	0.001	0.010	0.0	0.000	0.0	0.000	0.0	0.000	0.0101
Lifecycle Cost	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
NOx Emissions	0.0	0.000	0.004	0.017	0.0	0.000	0.0	0.000	0.017
Other Eco Impacts of Mats	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Other G'hse Gas Emissions	0.0007	0.006	Counted elsewhere		0.0	0.000	0.033	0.059	0.065
Pollution: Energy Con Inhabitation	0.005	0.042	0.053	0.223	0.0	0.000	0.039	0.070	0.335
Procurement	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Quality of Indoor Env: Pollution	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Quality of Indoor Env: Daylight	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Quality of Indoor Env: Ventilation	0.066	0.554	0.024	0.101	0.162	1.523	0.067	0.121	2.299
Recycling Construction Waste	0.00002	0.000	0.0	0.000	0.016	0.150	0.0	0.000	0.151
Recycling of Building	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Space Stds: Area	-0.022	-0.185	-0.040	-0.168	-0.00250	-0.024	-0.034	-0.061	-0.438
Space Stds: Volume	-0.022	-0.185	-0.040	-0.168	-0.00327	-0.031	-0.034	-0.061	-0.445
Thermal Performance	0.019	0.160	-0.001	-0.004	0.046	0.430	-0.010	-0.018	0.567
Use Recycled Materials	0.0	0.000	Counted elsewhere		0.006	0.056	0.0	0.000	0.056
Use Renewable Material	0.0	0.000	0.0	0.000	0.018	0.169	0.0	0.000	0.169
Utilisation of Local Resources	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000
Water Con: Construction	0.00006	0.001	0.0000002	0.0000008	0.00001	0.00009	0.000	0.000	0.0006
Water Con: Inhabitation	0.015	0.126	0.012	0.050	0.003	0.028	0.003	0.005	0.209
TOTAL	1.000	8.400	1.000	4.200	1.000	9.400	1.000	1.800	23.800

Table 18: Normalised weighting for each of the criteria, accounting for the Building Research Establishment's relative significance ratings

The impact of this upon the hierarchy of the criteria for the 'urban house in paradise' is summarised in the table below:

	Criteria	Weighting
Most:	Energy Consumption: Inhabitation	11.049
	Energy Generation: Inhabitation	2.923
	Q of I E: Ventilation and Air Tightness	2.299
	CO_2 Emissions: Inhabitation	2.234
	Ecological Weight: Embodied Energy	1.087
	Thermal Performance	0.567
	Design Life Span	0.399
	Pollution: Energy Consumption Inhabitation	0.335
	Ecological Weight: Embodied CO_2 Emissions	0.311
	Domestic Waste Recycling	0.214
	Deconstruction/Demolition: Recycling Materials	0.214
	Water Consumption: Inhabitation	0.209
	Use of Renewable Materials	0169
	Recycling Construction Waste	0.151
	Density: Quantitative	0.141
	Carbon Intensity	0.134
	Energy Consumption: Construction Processes	0.116
	Ecological Significance of the Site	0.069
	Other Greenhouse Gas Emissions	0.065
	Use of Recycled Materials	0.056
	CO_2 Emissions: Construction Processes	0.034
	Nitrogen Oxide Emissions from Gas Boilers	0.017
	Green Space	0.010
	Water Consumption: Construction	0.001
	Construction Period	0
	Contextual Significance of the Site	0
	Density: Qualitative	0
	Diversity	0
	Lifecycle Cost	0
	Other Ecological Impacts of Materials	0
	Procurement	0
	Q of I E: Daylight	0
	Q of I E: Pollution	0
	Recycling of Building	0
	Utilisation of Local Resources	0
	Space Standards: Area	- 0.438
Least:	Space Standards: Volume	- 0.445

The impact that this had on the overall hierarchy is relatively small. The top five criteria remain the same, but Ecological Weight: Embodied Energy and CO_2 Emissions: Inhabitation swapped places within the top five. Thermal Performance rose three places to become sixth most significant. Another change within the most significant criteria was the rise of Domestic Waste Recycling and Deconstruction and Demolition: Recycling of Material into tenth and eleventh places respectively, above that of Water Consumption: Inhabitation. This is the only addition of new criteria to the most significant that the tool has been designed to assess, and occurred due to the high weighting attributed to natural resource depletion in the Building Research Establishment study, of 9.4. The criterion of Other Greenhouse Gas Emissions, however, dropped from one of the most significant, down into nineteenth place, due to the low weighting attributed to Ozone Depletion, of 1.8. Both the criteria of Use of Renewable Materials and Recycling Construction Waste rose in their overall significance, also due to the high weighting attributed to natural resource depletion. The only other change was that Ecological Significance of the Site rose slightly in the hierarchy. Without an understanding of the basis for the relative significance placed upon the parameters of natural resource depletion and ozone depletion by the Building Research Establishment study, it is difficult to comment upon their validity.

In overall terms the order of hierarchy of the criteria remained relatively constant; therefore the tool is still assessing the most significant criteria, with the only exception being Domestic Waste Recycling and Deconstruction and Demolition: Recycling of Material. This suggests that if the scope of the tool is extended to encompass the remaining criteria of the 'urban house in paradise', these two should be incorporated into the assessment first. However, it would be cautionary to note that the basis for the weightings developed by the focus groups might be based upon the perceived anthropocentric significance, or the importance of each in terms of human interest, and therefore undermine the thesis' Deep Ecological philosophical underpinning to the prioritising process. Before applying these weightings to the tool, it would be prudent to establish the basis of the focus group's assessment, or to undertake a similar analysis, establishing a Deep Ecological perspective to the process.

Just as the DETR research on species biodiversity could be incorporated into the Ecological Value of the Site benchmark, identified in 12.3.1, it could also be applied to the prioritising of the criteria. As such data could not be determined at the time of prioritising, degradation of species and habitat was amalgamated into the parameter of natural resource depletion on the basis that land is a resource, in part through its provision of habitat. The DETR's biodiversity data could be used to determine the relative contribution to reducing the destruction of species biodiversity by building upon brownfield land, as opposed to a specific type of greenfield land, or land of a lower ecological value in terms of habitat provision. Also the contribution made by reducing land consumption through the more efficient use of land achieved by higher densities, and through the provision of materials from a recycled source could be determined. Therefore, the parameter of Natural Resource Depletion could be separated into two, and the new parameter used to determine the relative contribution of the benchmarks to reducing the degradation of species biodiversity on the basis of habitat.

During the validation by specialist interview, Brundrett identified that the criterion of ventilation and air tightness could be split into two individual criteria. This was studied to determine the impact it had upon the overall hierarchy of the criteria. The prioritising process was repeated, determining the contribution to the reduction in impacts on the four parameters of ecological degradation, firstly for just the air tightness benchmark, and then just the ventilation benchmark. Because the two benchmarks are separated, their individual weightings drop in comparison to their combined total, and both fall below the Ecological Weight: Embodied Energy criterion. However, even separated from the Ventilation benchmark, adopting the benchmark of Air Tightness contributes over two and a half times the benefit in improving the ecological sustainability of the dwelling than achieving the very high levels of thermal insulation benchmarked under the Thermal Performance criterion.

In terms of potential significance to the house building industry, the research establishes that the most significant way in which to improve the ecological sustainability of the dwelling is to reduce the energy consumption during inhabitation, and, furthermore, that the most effective way to achieve that is through reducing air infiltration. This knowledge could be used to target improvements in the house building industry.

12.6 Conclusions on the Tool

The tool gives both an analytical and predictive way in which to evaluate a dwelling, informed from a Deep Ecological perspective. Triangulated validation has established its accuracy. The specialist interviews commented upon its pertinence and innovation upon existing assessment methods, and considered the weakest qualities to be the time taken to conduct an assessment and its onerous appearance on first sight.

The tool and benchmarks do consider criteria that are beyond the scope of Deep Ecology, such as space standards and programmatic diversity, which though relevant in terms of socio-economic sustainability are of anthropocentric value rather than ecocentric. It is recognised that Deep Ecology does not stand in opposition to these criteria, because it is as much a product of anthropocentric effort as it is motivated by an ecocentric foundation. What is proposed by the thesis is a philosophy of increased humility toward the natural environment through how the performance of dwellings is perceived. This was achieved through the Deep Ecological orientation to the prioritising (how it affects any ecosystems as equally as human interests); therefore the tool assesses dwellings from a Deep Ecological perspective.

The weightings enable the user of the tool to identify the most sustainable balance of priorities, and therefore to identify which of the benchmarks should be achieved at the expense of others to create the most ecologically sustainable solution. The tool, in particular in the spreadsheet format, reflects and embodies the interconnected approach demanded when considering sustainability.

The triangulated validation by literature review, drawn studies and specialist interviews conclude that the assessment tool is an accurate way in which to predict the performance of a dwelling. Elements such as embodied energy and the significance of air infiltration were identified as notable additions to existing assessment methods. In overall terms the tool was perceived as pertinent to current drives for innovation in the house building industry. Although considered acceptable, the weakest qualities were considered to be the time taken to conduct an assessment and its onerous appearance on first sight.

Some of the comments arising in the specialist interviews have already been integrated into the tool and its background research. The criterion of Quality of the Internal Environment: Ventilation and Air Tightness was separated, to determine the weightings of each when considered individually; also, the impact on the overall weightings of removing Energy Consumption: Inhabitation, as it is a determined factor, was considered. A check was made to ensure that the SAP methodology, used as the basis to calculate the Energy Consumption: Inhabitation benchmark was accurate for dwellings with very low energy consumption. Other issues are considered below in Potential Revisions to the Tool.

12.7 Potential Revisions to the Tool

Two principle revisions to the tool have been identified. Firstly would be to assess the thermal mass of the dwelling, and integrate this into the internal gains and space heating demand. Secondly, improving the interface with the user, by creating layers of depth to an assessment and the increased use of defaults, would reduce the time taken to conduct an assessment.

The thermal mass of the dwelling could be quantified by the tool with relative ease, by adapting the volume and density stages of the embodied energy calculation, which already determines the mass of material in the dwelling, and identifying which are on the internal side on the insulation. Combining this with standard values of the specific heat capacity of materials would determine the total thermal mass of the dwelling. This value could then be linked to the internal heat gains and then space heating demand, to account for the contribution of thermal mass to the annual energy consumption of the dwelling. For example, the specific heat loss from the dwelling can be determined from step 129 of the worksheet, and is identified in the spreadsheet; it was 0.646 $W.m^{-2}.K^{-1}$ for Drawn Study 7. If the mean external temperature over the heating season is taken as 6.1 °C, and the internal temperature of the dwelling is assumed to be 19 °C, the heating demand would be 8.33 $W.m^{-2}$. With a thermal mass benchmark of 0.18 $kWh.K^{-1}.m^{-2}$, as proposed above, the dwelling would store sufficient energy to meet this demand for 21 hours with each degree Kelvin that the mass loses. An approximate value for the rise in temperature of the thermal mass due to incidental gains could be determined from the total gains value, step 168 in the worksheet.

Creating quantified relationships between embodied energy, thermal mass and annual energy consumption during inhabitation would provide a detailed and highly valuable insight into the relationships in the lifecycle energy consumption of a dwelling. As these are not accounted for in any other energy consumption models, this would evolve the research into further contribution to knowledge. Furthermore, the embodied energy calculation could also be extended to account for materials used in services of the dwelling, such as the water pipes and wiring, in addition to the fabric.

Improvements to the interface between the user and the spreadsheet would respond to the comments raised during the validation by specialist critics that the time taken to conduct an assessment was quite long, particularly for commercial application, and its initial appearance was seen as onerous. This could be amended through nesting the assessment in a series of levels, as proposed by Cole.[18] For example, the initial assessment would determine the Energy Consumption: Inhabitation and Energy Generation: Inhabitation, which are the two most significant of the criteria in terms of reducing the ecological impact of the dwelling. Default values for air tightness, ventilation, thermal performance, internal gains and the efficiency of the heating system, which affect the overall energy consumption, would be assumed, and straight forward decisions made by the user, such as whether the construction technology is masonry or timber frame. The next level would then move down to refining these component parts, such as the air tightness target and the thermal performance of the various elements that make up the envelope of the dwelling. This latter step would be linked to the Ecological Weight: Embodied Energy so that any changes to the fabric or construction technology could relate to the embodied energy and consequent emissions. These proposals to amend the interface do not affect the assessment calculations themselves, only the order in which they are completed.

The tool has been designed to determine the performance of a dwelling in terms of the most significant eleven of the thirty-seven criteria that define the 'urban house in paradise'. Another further development of the research would be to expand the scope of the assessment to appraise a dwelling against all of the benchmarks. The work required in undertaking this has already commenced in part; as the interrelated links between all of the criteria have been identified, and the relevant algorithms quantifying those links between the most significant eleven criteria and all of the others determined in chapter 8.

12.8 Conclusions on Drawn Studies

The drawn studies were used, in part, to ensure that the development of the criteria, benchmarks and assessment tool was not abstract to the creative design process. They also served to determine if they impinged upon it, which only the Ecological Weight did. The correlation between the benchmarks for the Drawn Studies determined by the assessment tool and longhand, manual calculation give confidence that the algorithms within the tool are correct and accurate.

Although not all of the benchmarks were achieved in the drawn study, the analysis did not determine adequate justification that each benchmark could not be met in another situation, and therefore this did not constitute sufficient reason for altering the benchmark values for those criteria. The correlation between the values determined by the assessment tool and longhand calculation give confidence that the algorithms within the tool are correct, and that the spreadsheet does not contain errors.

[16] Cole, Raymond J. 'Emerging Trends in Building Environmental Assessment', *Building Research & Information*, Number 26 Issue 1, 1998.

The addition of a basement to Drawn Study 7 to accommodate water storage increased the embodied energy of the dwelling from 249.8 $kWh.m^{-2}.a^{-1}$ over the benchmark to 306.0 $kWh.m^{-2}.a^{-1}$. The relative significance of the criteria can be used to determine if, in terms of the overall ecological sustainability of the dwelling, this is beneficial, or if the basement should be omitted. The weighting for Ecological Weight: Embodied Energy is 0.306, over nine times that of Water Consumption: Inhabitation, at 0.033. Therefore it can be concluded that increasing the embodied energy by a fifth to achieve a benchmark with a weighting less than a ninth that of the embodied energy would not contribute to increasing the overall ecological sustainability of the dwelling. This demonstrates the value of an assessment methodology that incorporates a hierarchy to its criteria. Alternatively the benchmark could be considered too onerous; this is commented upon in 12.3.2 above.

Whilst achieving the ambition that the majority of benchmarks had no influence over the creative design of the dwelling, validation through the drawn studies suggested that the benchmarks for Ecological Weight: Embodied Energy and Embodied CO_2 might be increased to be more achievable; Drawn Study 7, which used the very low embodied energy approach of timber frame, struggled to achieve them. This could be construed as dictating construction technologies and raises issues of contextuality; achieving the Ecological Weight benchmarks would mean that masonry construction, unless using recycled materials from the demolition of a building in the surrounding area, could not be used. Thus the dwellings would not be able to respond to or adopt traditional construction technology or, more significantly, materiality. A restriction on the ability to respond to context may be perceived as inappropriate to urban sites, and contradict the intention that the criteria and benchmarks do not impinge upon the creative design process.

An alternative view would be that architecture is 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. Scott writes that, "The history of civilisation thus leaves in architecture its truest ... record."[17] Even the architecture of the free imagination of Libeskind is a representation of history, no where more embodied that in the Jewish Extension of the Berlin Museum. Given the current decimation of the planet's ecosystems, plundering of its resources, and pollution of the natural environment, it might be considered that the need for more ecologically responsive dwelling is more urgent than historicist contextualism; and therefore that the architecture of dwellings, their brief, theoretical underpinning, design,

[17] Scott, Geoffrey. *The Architecture of Humanism*, London: Methuen, 1961, p. 3.

materiality and construction should represent this, thereby becoming the architecture of a new paradigm. Furthermore, contextuality can be reflected in ways other than materiality, such as proportion and hierarchy.

Drawn Study 6 studied four different permutations of dwelling types and vertical scale for the masterplan to evaluate the impact upon the density benchmark. The value in this process is that a scale of urban form that achieves the Density: Quantitative benchmark can be seen in the context of a numerical value. It is acknowledged that the form shown is only one way in which the benchmark could be achieved, but is one that is of an appropriate scale to an urban site. The decision was taken to develop the masterplan on the basis of the plan with the closest density to the benchmark. It could be argued that for a site in close proximity to a city centre a higher density would be more appropriate;[18] however the decision is justified on the basis that the study will demonstrate the scale of built form required to achieve the benchmark value. Furthermore the benchmark is proposed as a minimum for urban housing, to increase the efficiency of land use; therefore it can be exceeded and still comply with the benchmarks of the 'urban house in paradise'.

12.9 Potential Applications and Further Development of the Research

Incorporating the assessment of thermal mass into the tool and using it to propose a balance between the benchmarks of Ecological Weight, Energy Consumption: Inhabitation and Thermal Mass would develop the research in a direction that would further contribute to knowledge. Whilst the impact of weightings for the four parameters of ecological degradation has been determined, the prioritising could be advanced in other ways. The contribution to increasing social and economic sustainability could be incorporated, and a sensitivity analysis undertaken.

Whilst a tentative benchmark for thermal mass has been proposed, further research would establish a more robust value, or substantiation of the existing one. The methodology to incorporate the effect of thermal mass into the Ecological Weight and Energy Consumption: Inhabitation benchmark calculations has been outlined; integrating this into the assessment tool will mean that the effects of high thermal mass can be seen on the annual, and therefore lifecycle, energy consumption as well as the embodied energy. This could then propose an optimum thermal mass benchmark, in the context of the Ecological Weight and

18 For example, such as scenario four on drawing 2 of 3 in Drawn Study Six, of 502 $p.ha^{-1}$.

Energy Consumption: Inhabitation benchmarks, to establish a balance between the three. This would develop the research in a direction that would further contribute to knowledge.

As has been identified above, prioritising the criteria could now be extended to include values for species and habitat destruction, from new research that has emerged since the calculations were done. However, this would be a relative value as it is based on flora, and therefore does not include animal species.

Also, the prioritising could be expanded to include a weighting on the perceived significance between the five parameters of environmental destruction: global warming, pollution, natural resource depletion, species and habitat destruction and ozone depletion, by including a weighting for the significance of the five in relation to each other. Although time did not permit the development of such weightings, during the research period the Building Research Establishment has developed a weighting structure based on a focus group analysis, which they published during the validation period. However, the effect of applying the Building Research Establishment's weightings to the prioritisation in the thesis was relatively negligible, as discussed earlier.

The prioritising of the criteria could be extended to include both social and economic spheres of sustainability. This would address the observation that at present it could be perceived as detrimental to the sustainability of the dwelling to increase space standards. Such a process, which might include subjective parameters, could be incorporated into the prioritising through the analytic hierarchy process, which was one specific reason for its adoption as a part of the methodology. However, this might divert the orientation away from the philosophy of Deep Ecology, which is not primarily concerned with issues that pertain exclusively to human welfare but to the overall sustainability of the planet as a natural system.

If the process of prioritising the criteria were to be taken further, another potential aspect of study would be to undertake a sensitivity analysis. This would study the effects that making changes to the criteria and any assumptions made in the prioritising methodology, such as the area of a dwelling, would have in terms of the overall significance ratings that have been determined. It would establish whether or not small changes, such as a slight change in the area of the dwelling or in the number of occupants, would significantly alter the hierarchy.

This would also sensitise the tool, in terms of the weightings used to calculate a final score, accounting for the overall performance against the different criteria.

Increasing the number of assessments that have been made using the tool would broaden the range of comparable benchmark performances and scores. The advantage of this is that an architect would be able to determine the relative performance of a project against a number of comparative dwellings, if the score were above or below that of the 'urban house in paradise'. Using the tool analytically, to test against existing projects for which the ventilation rate, embodied energy and energy and water consumption during inhabitation have been tested would validate the tool against built projects, in addition to broadening the range of comparable scores. A chart of the existing scores determined by the tool is given below; a retrospective analytical assessment of the Vale's dwelling in Southwell was undertaken as an example of a comparable benchmark.[19]

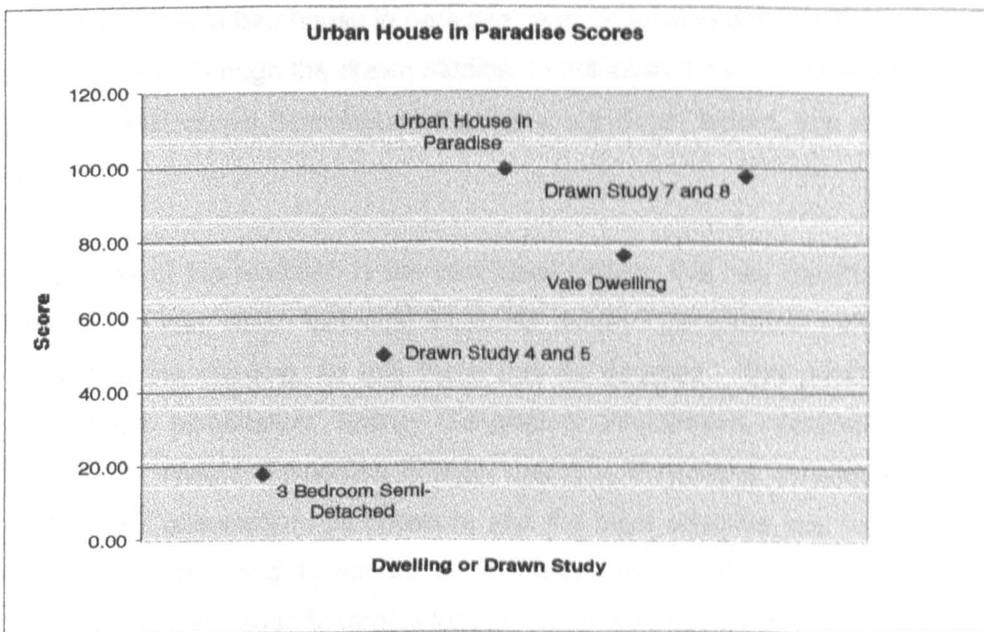

Figure 24: Scores derived through the assessment tool for a range of dwellings

[19] Refer to Case Study Two in chapter 5. Reasons for the Vale's dwelling having a score of 81.7 include the low energy consumption during inhabitation, very low water consumption and autonomy from the mains water supply.

12.10 Summary

Whilst the dwelling is individually small in scale compared to other building types, the domestic sector as a whole has a highly significant ecological impact. Wide-scale adoption of the generic performance standards of the 'urban house in paradise' would create tangible improvements in the overall sustainability of the United Kingdom, although it should be an integrated part of a wider drive to more sustainable lifestyles. The benchmarks define the 'urban house in paradise' as a fluid concept that can be innovated upon, and which could establish specific targets for the house building industry's role in achieving that goal.

The urban dwelling as a type through which to explore the ideal, ecologically sustainable dwelling has been demonstrated both as historically and contemporarily relevant. The antecedence of the generic dwelling as a source of architectural principles has also been identified. The ambition of the thesis, proposed in section 1.6, was to determine and value the criteria that define the 'urban house in paradise', and to develop a methodology through which to assess it; then, through the drawn studies, to establish if it is a realisable concept. The conclusions drawn above demonstrate that, to a significant extent, this ambition has been achieved.

One salient outcome of the research is the prioritised criteria; this has identified the most significant criteria that can, within technical feasibility, achieve the greatest reduction in the ecological impact of the dwelling, so that these can be targeted. The principal five are Energy Consumption: Inhabitation, Energy Generation: Inhabitation, Ventilation and Air Tightness, Ecological Weight: Embodied Energy, and CO_2 Emissions: Inhabitation. Most significant is Energy Consumption: Inhabitation, and the most effective way to achieve its benchmark is through reducing unwanted air infiltration by adopting the Air Tightness benchmark. These establish specific targets for the house building industry.

The assessment methodology designed to measure the performance of a dwelling against the benchmarks of the 'urban house in paradise' is both an analytical and predictive tool; it can be used both at the design stage and retrospectively to assess an existing dwelling. When used at the design stage it will enable an architect to identify both the performance of the dwelling, and to refine that performance to achieve the most ecologically sustainable solution. It embodies both hierarchy and interrelation between criteria; both identified omissions in first generation assessment methods.

If a wide scale adoption of the benchmarks of the 'urban house in paradise' were initiated, significant reductions in environmental impact could be made. For example, the present level of CO_2 emissions from domestic sources is approximately 157 million tonnes, and the Government's goal, following the Kyoto Protocol, is to reduce this to approximately 134 million tonnes by the year 2010, a reduction of 23 million tonnes.[20] If the CO_2 Emissions: Inhabitation benchmark was applied to all of the 3.8 million new dwellings required by 2021, the total reduction in CO_2 emissions would be 12.8 million tonnes per annum, or 50 percent of the 2010 target.[21] The Government claims to be on course to reduce CO_2 emissions by 23 percent of 1990 levels by 2010,[22] although there is contention over that prediction.[23] If the contribution to reducing CO_2 emissions effectuated by adopting the benchmark were added to that, the total reduction would be 31 percent of 1990 levels;[24] this would be over half way to achieving the 60 percent reduction identified by the IPCC as necessary by 2050 to stabilise the quantity of greenhouse gases present in the atmosphere.[25] This demonstrates both the potential value of adopting the benchmarks of the 'urban house in paradise' for the United Kingdom's sustainability agenda, and the onerous task that agenda has unless radical improvements in the sustainability of our lifestyles are made.

If the benchmarks of energy consumption, energy generation and CO_2 emissions during inhabitation, three of the most significant five, were achieved in 3.8 million new dwellings this would save 2.0 million tonnes of coal, 6.6 million tonnes of natural gas, 0.1 million tonnes of petroleum and 16.3 million tonnes of CO_2 emission per annum. However, the additional capital cost of achieving those reductions, based on the cost estimate of Drawn Study Seven, would be £134.9 billion,[26] which is 29 times the Government's proposed

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[20] 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.

[21] The reduction from 50.4 to 10.7 $kgCO2.m^{-2}.a^{-1}$ is multiplied by the area of a typical 3 bedroom semi-detached dwelling, to give an annual reduction per dwelling of 3.3745 tonnes. Multiplied by 3.8 million dwelling equates to an annual reduction of 12,823,100 tonnes.

[22] Department of the Environment, Transport and the Regions. *Climate Change – Draft UK Programme*, London: HMSO, 2000.

[23] Friends of the Earth. *Apocalypse Now*, London: Friends of the Earth, October 2000.

[24] The reduction of 12.8 million tonnes is 7.6 percent of the total CO_2 emissions arising from the United Kingdom in 1990, of 167.5 million tonnes. Department of the Environment, Transport and the Regions. *Climate Change – Draft UK Programme.*

[25] Intergovernmental Panel on Climate Change. *The IPCC Scientific Assessment*, Cambridge: Cambridge University Press, 1996; and Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998.

[26] The second cost option prepared by Davis Langdon Everest, excluding the basement, is used here as it still achieves the Energy Consumption: Inhabitation, Energy Generation: Inhabitation and CO_2 Emissions: Inhabitation benchmarks used in this example; this is used in comparison to the option based on the dwelling built using traditional construction methods.

spending on housing for 2003/04.[27] As the 3.8 million new dwellings will take up to 2021 to be built, dividing £134.9 billion across 20 years would equate to an annual cost of £6.7 billion, or 1.5 times the Government's proposed annual spending. This demonstrates the reduction in impact upon the natural environment that the wide-scale adoption of those benchmarks could have, but also the capital investment required in achieving it.

The 'urban house in paradise' represents an ideal, a dwelling radically more sustainable in a Deep Ecological sense than those produced today, and therefore one with a much more symbiotic relationship with nature. However, this is not to say that the benchmarks proposed cannot be improved upon; for example, a dwelling could produce significantly more energy than it consumes, and be built with greater reductions in embodied energy. The notion of continuous improvement is central to the philosophy of benchmarking. Therefore, the 'urban house in paradise' is something of a fluid concept, one that can continually be improved and innovated upon; its fluidity epitomises the appropriateness of the generic framework of benchmarks to the pluralistic nature of the creative design process. The benchmarks presented here represent the 'urban house in paradise' at this point in time, potentially on the cusp of a paradigmatic shift, as the sustainability of dwellings becomes an issue of paramount significance.

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[27] Department of the Environment, Transport and the Regions. *Our Towns and Cities: The Future – Delivering an Urban Renaissance*, London: HMSO, November 2000.

Consolidated Notes

1.0 Introduction

[1] Koolhaas, Rem and Bruce Mau. *S, M, L, XL*, Rotterdam: 010 Publishers, 1995, p. 969.
[2] Urban Task Force. *Towards an Urban Renaissance – Final Report of the Urban Task Force*, London: E & F N Spon, 1999.
[3] Department of the Environment, Transport and the Regions. *Our Towns and Cities: The Future – Delivering an Urban Renaissance*, London: HMSO, November 2000, p. 29.
[4] Berlin Declaration on the Urban Future website, 21 August 2000: www.urban21.de/english/03-homepage/declaration.htm
[5] European Commission website, 26 March 1999:
www.europa.eu.int/comm/dg11/urban/home_en.htm
[6] Department of the Environment, Transport and the Regions. Op. Cit.
[7] Koolhaas, Rem and Bruce Mau. Op. Cit.
[8] The Etruscan derived *urbs* replaced the older Indo-European word, *tota* for city. Rykwert, Joseph. *The Idea of a Town*, Cambridge, Massachusetts: The MIT Press, 1988.
[10] The founder of the town, having gathered his followers at an agreed point, would set his plough so that all of the earth would fall inside the furrow, toward the town. With his head covered, he ploughed to define the site of the city. When he arrived at any points on the boundary that were to become gates, he took the plough from the ground and carried it across the width of the gate; it is this carrying (*portare*) that is attributed to the root of *porta*, a gate.
[11] The origins of urban culture preceded the genesis of the term *urban*. Herodotus's account of the rise of Deioces to power over the Medes, written around the fifth century BC, gives a rational account of the transition from village culture to urban culture that is free of the religious ideas that affect the accounts of late Stone and Early Bronze Ages. In a position of empowerment, Deioces directed the Medes, who were previously settled in dispersed villages, to build one city. Then, within the confines of that city, Deioces built fortifications of his own, around his palace; "... in lessening the physical distance by concentrating population in the city, Deioces took care to increase the psychological distance by isolating himself and by making access to his person formidable. This combination of concentration and mixture, with isolation and differentiation, is one of the characteristic marks of the new urban culture." Mumford, Lewis. *The City in History*, London: Penguin Books, 1991, p. 61.
[12] Department of the Environment. *Climate Change: Our National Programme for CO_2 Emissions*, London: Department of the Environment, 1992; and Department of the Environment. *The UK Environment*, London: HMSO, 1992.
[13] Department of the Environment, Transport and the Regions website, 2 July 1999:
www.housing.detr.gov.uk/information/keyfigures/index.htm
[14] Department of the Environment, Transport and the Regions. *A Better Quality of Life – A Strategy for Sustainable Development for the United Kingdom*, London: HMSO, May 1999.
[15] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds: Leeds Metropolitan University, 1998.
[16] Springer, Dr Otto (ed). *Langenscheidt's Encyclopaedic Dictionary of the English and German Languages – Part II*, Langenscheidt, 1997.
[17] Heidegger, Martin. 'Building, Dwelling, Thinking'; in Leach, Neil (ed). *Rethinking Architecture - A Reader in Cultural Theory*, Routledge, 1997, p. 102.
[18] Ibid, p. 103.
[19] Dripps, R. D. *The First House - Myth, Paradigm, and the Task of Architecture*, The MIT Press, 1997, p. 4.
[20] The urban dwelling, conceived of as a piece of architectural design like the rural villa, began, for the first time since the end of the Roman era, to reappear in sixteenth century Italy, through an impetus generated by increased affluence and the aspirations of the Renaissance. This re-emergence is marked in time by the Italian architect Sebastiano Serlio's (1475-1554) *Book VI* on domestic architecture, drafted between 1551 and 1553 but not published until 1967, which is acknowledged as the first treatise on the typology of domestic architecture in the Western World, and includes the specific distinction between the country and urban dwelling. Rosenfeld, Myra Nan. *Serlio on Domestic Architecture*, Dover Publications Inc., 1996.
[21] Cicero, (translated by Niall Rudd). *The Republic*, Oxford University Press, 1998, p. 19.

[22] Boyer, M. Christine. *The City of the Collective Memory – Its Historical Imagery and Architectural Entertainments*, Cambridge Massachusetts: The MIT Press, 1998.
[23] Alberti, L. B. *De Architettura IX*, in Borsi, Franco. *Leon Battista Alberti – Complete Edition*, Oxford: Phaidon, 1977, p. 326.
[24] Kollhoff, Hans. 'Urban Building Versus Housing,' *Lotus*, Number 66, p. 101.
[25] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames and Hudson Limited, 2000.
[26] Ibid.
[27] "In The Epic of Gilgamesh, Utnapishtim, the Sumerian equivalent of Noah, is discovered 'taking his ease on his back' in a place where, '... the croak of the raven was not heard, the bird of death did not utter the cry of death, the lion did not devour, the wolf did not tear the lamb, the dove did not mourn, there was no widow, no sickness, no old age, no lamentation.' " Quoted in Turner, Paul's introduction to More, Thomas. *Utopia*, London: Penguin Books, 1965, p. 16.
[28] Frankfort, Henri. *Kingship and the Gods*, Chicago University Press, 1948, p. 342; in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995.
[29] Linden, Eugene. 'The Big Meltdown', *Time*, Volume 156 Number 10, 4 September 2000, p. 66.
[30] Melting ice in the Arctic caused by a temperature rise of a few degrees would create a layer of freshwater floating on top of the saltwater in the north Atlantic, preventing cooler water sinking, this would hinder or arrest the cyclic ocean current which brings warm water from the Gulf Stream.
[31] In terms of proposing more sustainable patterns of habitation, in which man is more harmonious with nature, it could be possible to take the natural environment itself as a precedent: "Imagine an industrial system that has no provisions for landfills, or smokestacks. If a company knew that nothing that came into its factory could be thrown away, and that everything it produced would eventually return, how would it design its components and products? The question is more than a theoretical construct, because the earth works under precisely these strictures." Hawken, Paul, Amroy Lovins and L. Hunter Lovins. *Natural Capitalism – The Next Industrial Revolution*, London: Earthscan, 1999.
[32] Carson, Rachel. *Silent Spring*, Boston: Houghton Mifflin, 1962.
[33] Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala Publications Inc., 1995
[34] World Commission on Environment and Development. *Our Common Future (The Brundtland Report)*, Oxford: Oxford University Press, 1987, p. 43.
[35] Snyder, Gary. 'Culture or Crabbed,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala Publications Inc., 1995, p. 49.
[36] Foreman, Dave. 'The New Conservation Movement,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala Publications Inc., 1995, p. 52.
[37] Ibid.
[38] Capra, Fritjof. 'Deep Ecology - A New Paradigm,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala Publications Inc., 1995.
[39] Sessions, George (ed). Op. Cit.
[40] Ibid., p. 20.
[41] Rykwert, Joseph. *On Adam's House in Paradise - The Idea of the Primitive Hut in Architectural History*, Cambridge, Massachusetts: The MIT Press, 1981, p. 13.
[42] Ibid.
[43] Ibid.
[44] Pérez-Gomez, Alberto. Architecture and the Crisis of Modern Science, Cambridge Massachusetts: The MIT Press, 1996, p. 62.
[45] Of course, the influence of the man-made has always been an intrinsic part of paradise; for example, Eden was a garden which man was to tend. Also, Milton's heaven in *Paradise Lost* contains many architectural and urban elements: "The hasty multitude / Admiring enter'd, and the work some praise / And some the Architect: his hand was known / In Heav'n by many a Tow'red structure high, / Where Scepter'd Angels held their residence, ..." Milton, John. *Paradise Lost*, London: Penguin Books, 1989, p. 25.
[46] The protocol, or tool, will be validated, in order to ensure its accuracy, through different means: analysis against the proposed final drawn study that is an integral part of the research methodology, and through critiques with relevant specialist. This will ensure confidence in both the performance benchmark levels proposed by the matrix of benchmarks, the interrelationship between those benchmarks, and the working process of the assessment tool itself.
[47] Duffy, Dr Francis. 'Our Future: The Analysis is Done, Now is the Time for Action', in *RIBA Strategic Study – Volume Three*,

[48] Personal communication from John Whitelegg, Professor of Environmental Studies, Liverpool John Moores University, 28 November 2000.
[49] Kuhn, Thomas. *The Copernican Revolution*, The Harvard University Press, 1957.
[50] Hall, Peter. *Cities in Civilisation*, Weidenfeld & Nicolson, 1998.
[51] In *The Structure of Scientific Revolutions*, the term becomes much more specific: "Kuhn compared the shift from one paradigm to another to a gestalt flip ... But for Kuhn the shift is more profound; he added that, 'the scientist does not preserve the gestalt subject's freedom to switch back and forth between ways of seeing.' " Weinberg, Steven. 'The Revolution That Didn't Happen,' *The New York Review*, 6 May 1999, p. 48. For Kuhn the theory of each successive paradigm, or period of normal science, was incommensurate with the previous ones. The theory and culture of one paradigm changes so significantly that after a scientific revolution it becomes virtually impossible to see things as they had been seen under the previous paradigm.

In his theories on the development of education, based on developmental cognitive science, Howard Gardener seeks to develop an approach to teaching that is more responsive to the way which children learn. "To many psychologists, the development of knowledge in children looks a lot like the development of knowledge in science. Children seem to construct successive theories of the world that are the product of both their earlier theories and new evidence." Gopnik, Alison. 'Small Wonders,' *The New York Review*, 8 October 1998, p. 34. In other words, children change an existing understanding of a concept on the basis of new information they receive, and that new understanding is more accurate than the previous. This demonstrates a remarkable similarity between the nature of Kuhn's paradigm and the nature of human learning, and therefore the core of being human.
[52] Kuhn, Thomas. *The Structure of Scientific Revolutions (Third Edition)*, London: The University of Chicago Press, 1996, p. 19.
[53] For example, the initial drawn studies generated rudimentary values in terms of space standards, energy performance, in terms of thermal efficiency and cost, construction cost and waste. These figures were then refined and developed through input from other sources, and via critical analysis of the studies toward improving these standards.
[54] The UHDPD is a set of 128 criteria derived, during the initial stages of this study, to assess urban housing projects on a European and worldwide scale. These criteria are both objective and subjective, and it is the objective that incorporates performance characteristics. A full list of the UHDPD criteria, including the subjective, which assess the architectural quality of a project, is contained in Annexe 4.0.
[55] In addition, in the context of the Construction Taskforce's avocation of increased standardisation in the construction industry, the thesis will also consider the inherent benefits to these benchmark values of increased standardisation and industrialisation to the sustainable performance of an urban dwelling.
[56] Bradley Guy, G. and Charles J. Kibert. 'Developing Indicators of sustainability: US Experience,' Building *Research & Information*, Number 26 Issue 1, 1998, p. 40.
[57] Rao, Susheel, Alan Yates, Deborah Brownhill and Nigel Howard. *EcoHomes – The Environmental Rating for Homes*, London: Construction Research Communications Limited, 2000.
[58] Environmental criteria can be prioritised from a variety of standpoints, for example: their significance to ecological impact in local, regional and global terms, and linkages and potential synergistic effects with others. Particularisation is likely to create specific clustering and emphasis between criteria within the tool, prioritising them against each other; therefore, whilst the benchmarks will provide the generic basis for the 'urban house in paradise', the tool will facilitate the process of prioritisation. The notion of prioritising assessment criteria is captured through the process of placing weightings upon them within the matrix, as a part of the methodology in establishing a single overall measure of performance.
[59] Wedley, William C. 'Combining Qualitative and Quantitative Factors - An Analytic Hierarchy Approach,' *Socio-Economic Planning Science*, Volume 24 Number 1, 1990.
[60] Refer to Annexe 1.0, An Individual Analysis of Existing Environmental Assessment Techniques.

2.0 An Appraisal of Existing Modelling Techniques

[1] Wood, Christopher. *Environmental Impact Assessment - A Comparative Review*, Longman Scientific & Technical, 1995, p. 12.
[2] Cole, Raymond J. 'Emerging Trends in Building Environmental Assessment Methods,' *Building Research & Information*, Number 26 Issue 1, 1998; and Curwell, Steve and Ian Cooper. 'The Implications of Urban Sustainability,' Building *Research & Information*, Number 26 Issue 1, 1998.

[3] Curwell, Steve and Ian Cooper. Op. Cit.
[4] Sources for these assessment tools are varied, but include direct sourcing of the tools themselves and, Cole, Raymond J. Op. Cit., 1998, p. 6.
[5] Department of the Environment, Transport and the Regions website, 22 August 2000: www.detr.gov.uk/housing/information/hqi/index.htm
[6] Golton, Bryn. 'Sustainable Development, the 'Green' Agenda and Building'
[7] Cole, Raymond J. 'Prioritising Environmental Criteria in Building Design and Assessment,' in Brandon, P. S., P. L. Lombardi and V. Bentivegna. *Evaluation of the Built Environment for Sustainability*, E & FN Spon, 1997.
[8] IVAM website, 22 July 2000: www.ivambv.uva.nl/IVAM
[9] Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. *Factor Four - Doubling Health, Halving Resource Use*, London: Earthscan Publications Limited, 1998.
[10] 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.
[11] These impacts include: shortage of raw materials, ecological damage caused by extraction of raw materials, energy consumption at all stages (including transport), water consumption, harmful emissions, global warming and acid rain, and waste.
[12] Rapoport, Amos. House, Form and Culture, New Jersey: Prentice-Hall, 1969.
[13] Lindberg, Erik et al. 'Residential-Location Preferences Across the Life Span', *Journal of Environmental Psychology*, Issue 12, 1992.
[14] This is assessed in terms of adequate floor to floor height, appropriateness of core and structure location to adaptation, and ease of changing dwelling layouts to accommodate changing household requirements. Cole, Raymond J. and Nils K. Larsson. 'GBC '98 and GB Tool: Background', *Building Research & Information*, Volume 27 Number 4/5, 1999.
[15] A default value of 60 years is assumed, but this can be varied.
[16] Interview conducted with Jane Anderson of the Building Research Establishment's Sustainable Construction Unit, 16 August 2000.
[17] Koolhaas, Rem. 'The Generic City', in Koolhaas, Rem and Bruce Mau. *S, M, L, XL*, Rotterdam: 010 Publishers, 1995.
[18] Department of the Environment, Transport and the Regions website, 22 August 2000: www.detr.gov.uk/housing/information/hqi/index.htm
[19] Ibid.
[20] Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995.
[21] This was recognised as a shortcoming of *Envest*'s methodology in an interview conducted with Jane Anderson of the Building Research Establishment's Sustainable Construction Unit, 16 August 2000.

3.0 Criteria of the Tool

[1] It should be borne in mind that due to the interrelation between the criteria, they should not be considered as relating to only one specific period of the lifecycle. Taking insulation as an example, the depth of insulation specified at the design stage will affect the quantity of material used and therefore the energy embodied in the dwelling's construction, and also the energy consumed by the dwelling during its period of inhabitation.
[2] Biswas, Ramesh Kumar (ed). *Innovative Austrian Architecture*, New York: Springer-Verlag Wien, 1996.
[3] Comparable to that of Christopher Alexander's *A Pattern Language*; Alexander, Christopher, S. Ishikawa and M. Silverstein. *A Pattern Language: Towns, Buildings, Construction*, New York: Oxford University Press, 1997.
[4] Increasing the ecological sustainability of the dwelling will require increasing the cyclic loop, and minimising the linearity identified.
[5] For example, the Building Research Establishment's *General Information Report 38*, of ultra low energy dwelling in the United Kingdom and Europe, covers a range of dwelling types from the individual dwelling, to terraced units, to multi-occupancy blocks of flats. The criteria contained within this document were, therefore, appropriate to each of these dwelling types.
[6] A full list of the Urban Housing Design and Procurement Database (UHDPD) criteria is contained in Annexe 4.0.

4.0 Benchmarking the 'Urban House in Paradise'

[1] Zairi, Mohamed. *Benchmarking for Best Practice – Continuous Learning Through Sustainable Innovation*, London: Butterworth Heineman, 1996.
[2] Codling, Sylvia. *Benchmarking*, Hampshire: Gower Publishing Limited, 1998.
[3] Quoted in Camp, Robert C. *Benchmarking – The Search for Industry Best Practices that Lead to Superior Performance*, Milwaukee: ASQC Quality Press, 1989, p. 10.
[4] Eccles, Robert G. 'The Performance Measurement Manifesto', *Harvard Business Review*, January-February 1991, p. 131.
[5] These initiatives included the World Class Standards Network and Framework for European Benchmarking. Codling, Sylvia. Op. Cit.
[6] McNair, C. J. and Kathleen H. J. Leibfried. *Benchmarking – A Tool for Continuous Improvement*, New York: Harper Collins Publishers, 1992, p. 19.
[7] Chairman of the Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry.
[8] Latham, Michael. *Constructing The Team: Joint Review Of Procurement And Contractual Arrangements In The United Kingdom Construction Industry: Final Report*, London: HMSO, 1994.
[9] The Construction Task Force. *Rethinking Construction*, London: HMSO, July 1998.
[10] Ibid.
[11] Zairi, Mohamed. Op. Cit. p. 35.
[12] Construction Best Practice Programme website, 1 May 2000: www.cbpp.org/themes/suscon
[13] Weizsacker, Ernst von, Amory B. Lovins and L. Hunter Lovins. Op. Cit.
[14] Department of the Environment. *Household Growth: Where Shall We Live?*, presented to Parliament by the Secretary of State for the Environment, HMSO, 1996.
[15] Department of the Environment, Transport and the Regions website, 2 July 1999: www.housing.detr.gov.uk/information/keyfigures/index.htm
[16] Weizsacker, Ernst von, Amory B. Lovins and L. Hunter Lovins. Op. Cit.
[17] Ibid., p. xxi.
[18] Lowe, Robert and Malcolm Bell. *Towards Sustainable Housing: Building Regulation for the 21st Century*, Leeds Metropolitan University, 1998.
[19] Department of the Environment, Transport and the Regions. *Our Towns and Cities: The Future – Delivering an Urban Renaissance*, Op. Cit.
[20] The housing need figure for England was sourced from the Department of the Environment, Transport and the Regions website: www.housing.detr.gov.uk/information/keyfigures/index.htm, 2 July 1999; the figures for other European countries were established through personal communication the relevant government body for each country: Danish Ministry of Housing & Urban Affairs, Finnish Ministry of the Environment, Dutch Embassy in London, Norwegian Building Research Institute, and the Swedish National Board of Housing.
[21] The cause of the increase is attributed to an increase in smaller households due to the combined factors of the young marrying and cohabiting later, increases in divorce, and the elderly living longer, as well as population increase.
[22] Department of the Environment, Transport and the Regions. *Our Towns and Cities: The Future – Delivering an Urban Renaissance*, London: HMSO, November 2000.
[23] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. *Europe's Environment - The Dobris Assessment*, European Environment Agency, 1995.
[24] Zairi, Mohamed. Op. Cit.

5.0 Case Studies of European Housing Projects that Demonstrate a Number of the Performance Benchmarks

[1] It was intended to use a European dwelling from outside the United Kingdom as one of the case studies; however, due to a lack of sufficiently detailed information to permit analysis of the performance against a number of the criteria, this desire could not be fulfilled.

[2] Dr Roaf is a senior lecturer in architecture at Oxford Brookes University.
[3] Built in masonry construction, the traditional brick and 150 mm concrete block walls have a cavity filled with 150 mm fibre insulation blocks; the roof is concrete tiled, with between 200 to 250 mm sprayed fibre over wool quilt insulation. The concrete ground floor, insulated with 160 mm insulation beneath, and concrete beam and block first floor provide a significant proportion of the thermal mass; in addition to this, internal walls are constructed from 150 mm concrete block.
[4] Lesniewski, J. and D. Thorpe. *Future Homes*, Machynlleth: Centre for Alternative Technology Publications, 1997.
[5] BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, HMSO, February 1996.
[6] Lesniewski, J. and D. Thorpe. Op. Cit.
[7] Ibid.
[8] 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*, ETSU, 1999.
[9] Ibid.
[10] Ibid.
[11] Research Steering Group of the Building Surveyors Division and the Building Research Establishment. *Life Expectancies of Building Components*, Royal Institute of Chartered Surveyors, August 1992.
[12] For comparison, the values for the ground floor are 0.19 and 0.13 $W.m^{-2}.K^{-1}$, and windows are 1.3 and 0.8 $W.m^{-2}.K^{-1}$, for the Oxford Solar House and 'urban house in paradise' respectively.
[13] Vale, Brenda and Robert. *The Autonomous House – Design and Planning for Self-Sufficiency*, London: Thames and Hudson, 1975.
[14] Brick and dense concrete block walls have 250 mm of insulation in a fully filled cavity. The clay pantile roof is insulated with 500 mm of cellulose fibre, underlined with an exposed softwood structural decking in order that the habitable space extends into the roof void to maximise use of the enclosed space. Ground and first floors are both constructed from concrete beam and blocks to add to the thermal mass, which is increased further by dividing the rectangular plan into bays with loadbearing concrete block crosswalls.
[15] Further detailing to ensure airtight construction includes the roof being underlined with a reinforced polyethylene air and vapour barrier, which is carefully detailed to meet the wet plaster on the walls to achieve a seal. The plaster on the walls was brought right down to meet the screed on the concrete block floors. Wet construction is seen as advantages in airtight construction. Placing insulation in the plane of the roof meant that there were few penetrations through the air and vapour barrier. Window and door openings are carefully sealed. This was achieved in three stages: windows and doors with in-built seals around opening components were specified; these were fitted into plywood wall boxes, and a CFC-free expanding foam used to put a compressible airtight seal around the inner edge of each frame, between the frame and plywood box; finally the boxes themselves were sealed to the internal face of the inner leaf with silicone seal prior to the walls being plastered. BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, London: HMSO, February 1996.
[16] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.
[17] Ibid.
[18] BRECSU. 'Review of Ultra-Low-Energy Homes - Ten UK Profiles in Detail,' *General Information Report 39*, London: HMSO, March 1996, p. 26.
[19] Voelcker, Adam. 'Vale of Health', review of *The New Autonomous House – Design and Planning for Sustainability*, by Robert and Brenda Vale, in *The Architectural Review*, 1241, July 2000.
[20] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*.
[21] Ibid.
[22] BRECSU. 'Review of Ultra-Low-Energy Homes - Ten UK Profiles in Detail,' *General Information Report 39*, London: HMSO, March 1996.
[23] 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; and Urban Task Force. *Towards an Urban Renaissance*, London: E & F N Spon, 1999.

6.0 Analysis of Comparative Models for the Tool

[1] Department of the Environment, Transport and the Regions. The Government's Standard Assessment Procedure for Energy Rating of Dwellings, Building Research Establishment, 1998; and Anderson, B. R. *Energy Assessment for Dwellings using BREDEM Worksheets*, IP13/88, Building Research Establishment, November 1988.
[2] L. D. Shorrock and B. R. Anderson. *A Guide to the Development of BREDEM*, IP 4/95, Building Research Establishment, February 1995.
[3] Personal communication, Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.
[4] IVAM website, 22 August 2000: www.ivambv.uva.nl/IVAM/therma_d/EQ-paper.html
[5] Cole, Raymond J. 'Prioritising Environmental Criteria In Building Design and Assessment', in Brandon, P. S., P. L. Lombardi and V. Bentivegna. Evaluation of the Built Environment for Sustainability, E & F N Spon, 1997.
[6] This is primarily restrictive through the limited variety of construction methods that can be selected.
[7] Interview conducted with Jane Anderson of the Building Research Establishment's Sustainable Construction Unit, 16 August 2000.
[8] Cole, Raymond J. and Nils K. Larsson. 'GBC '98 and GB Tool: Background', *Building Research & Information*, Volume 27 Number 4/5, 1999.

7.0 Prioritising the Criteria of the Tool

[1] Snyder, Gary. 'Culture or Crabbed,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, Shambhala Publications Inc., 1995, p. 49. In partnership with the Deep versus Shallow question of the intrinsic value of all species for their own sake, is the question of, "... what, if any, ethical obligations humans [have] to the nature of other species." Foreman, Dave. 'The New Conservation Movement,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, Shambhala Publications Inc., 1995, p. 52.
[2] Ibid.
[3] Capra, Fritjof. 'Deep Ecology - A New Paradigm,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, Shambhala Publications Inc., 1995.
[4] Ibid., p. 20.
[5] Naess, Arne. 'The Deep Ecological Movement – Some Philosophical Aspects,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, Shambhala Publications Inc., 1995, p. 72.
[6] Prior, Josephine J. and Paul B. Bartlett. Environmental Standard - Homes for a Greener World, Building Research Establishment, 1995.
[7] Cole, Raymond J. 'Prioritising Environmental Criteria in Building Design and Assessment,' in Brandon, P. S., P. L. Lombardi and V. Bentivegna. *Evaluation of the Built Environment for Sustainability*, E & F N Spon, 1997.
[8] Over simplification is a potential weakness of Ecocost assessment, which reduces the very complex issue of ecological degradation into a number of relatively simple equations. These produce a single score between 1 and 0, where 1 represents the ecological degradation of the environment, and zero a healthy, sustainable planet.
[9] Ibid.
[10] The five topics are: ozone layer protection, environmental impact of energy use, indoor environmental quality, resource conservation, and site and transportation.
[11] Ibid.
[12] 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.
[13] The identified shortcoming of this unit of assessment is that as an abstract, dimensionless value, not considered in terms of conventional units, it will only identify the ecological benefits of reducing, for example, energy consumption. Because no quantification of that energy reduction can be identified the wider benefits in the relationship between additional capital cost and lifecycle cost saving, which might provide a greater incentive for creating a more sustainable building, cannot be considered. Also, whilst the Ecopoint will indicate if one building is more sustainable than another it does not enable the user to determine why that is.

[14] For example, predicating the prioritisation on the level of CO_2 emission attributed by each criterion will create a tool that is orientated toward the total reduction of CO_2 emission created by the benchmarks, as opposed to one that measures the effects of the benchmarks on an overall view of ecological sustainability. Also, there is no single parameter against which sustainability can be defined due to the diversity of effects that contribute to environmental degradation.

[15] Naess, Arne. 'The Shallow and the Deep, Long-Range Ecology Movements,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, Shambhala Publications Inc., 1995.

[16] Naess, Arne. 'The Deep Ecological Movement – Some Philosophical Aspects,' Op. Cit.

[17] The next step, were the process of prioritising the criteria to be taken further, would be to undertake a sensitivity analysis. This would study the effects that making changes to the criteria and the assumptions made would have in terms of the overall priority rating that has been determined. It would establish whether or not small changes, such as a slight change in the area of the dwelling or in the number of occupants, would significantly alter the hierarchy of priority.

[18] Cole, Raymond J. Op. Cit.

[19] Wedley, William C. 'The Analytic Hierarchy Process,' *Socio-Economic Planning Science*, January 1990.

[20] In the methodology used to derive the Ecopoint, launched after the prioritising was completed, a process of normalisation was used to convert environmental impacts into dimensionless, and therefore comparable, values. Edwards, Suzy of Building Research Establishment's Sustainable Construction Unit. Speaking at *Envest – The Environmental Assessment of Office Buildings* seminar, Glaziers Hall, London, 10 May 2000. That a similar methodology has been used in a kindred, although not identical, process gives confidence in its adoption here. As identified, a shortcoming of Ecopoints is that a variety of impacts have been compressed into a single, somewhat abstract score, which does not allow the user to understand the true nature of the environmental impact the building is making; this was borne in mind when considering how to apply the weighting value within the assessment process.

[21] Wedley, William C. Op. Cit.

[22] Ibid.

[23] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. *Europe's Environment - The Dobris Assessment*, European Environment Agency, 1995.

[24] Restricting the parameters to those in which an effect could be directly attributed to a dwelling provided a filter through which to reduce the number to be selected for the purposes of prioritising from the 35 contained within the Dobris assessment report; indirect parameters include transport and agriculture.

[25] Legget, J. (ed). *Global Warming*, Oxford: Oxford University Press, 1990, p. 480.

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

[27] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.

[28] Intergovernmental Panel on Climate Change. T*he IPCC Scientific Assessment*, Cambridge University Press, 1996.

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

[30] Department of the Environment, Transport and the Regions. *Climate Change – Draft UK Programme*, London: HMSO, 2000.

[34] 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*, DETR, 1998.

[35] 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.

[36] 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.

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

[38] Jouzel, J. et al. 'Vostock Ice Core: A Continuous Isotope Temperature Record over the Last Climatic Cycle,' *Nature*, Number 329.

[40] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.

[41] Ibid., p. 519.
[42] Snyder, Gary. 'Four Changes,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, Shambhala Publications Inc., 1995, p. 143.
[43] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.
[44] Naess, Arne. 'The Deep Ecological Movement – Some Philosophical Aspects,' in Sessions, George (ed). *Deep Ecology for the 21st Century*, Shambhala Publications Inc., 1995.
[45] Particulate matter was included in addition to the pollutants used in the Dobris Assessment as it is a product of the combustion of fossil fuels, which relates significantly to the criteria of the 'urban house in paradise'. Department of Trade and Industry. *Digest of United Kingdom Energy Statistics 1998*, London: HMSO, 1998.
[46] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.
[47] Drucker, Peter. *Innovation and Entrepreneurship*, 1985, p.30.
[48] UN Environment Programme. Press Release: *Human's Destroying the Earth's Biodiversity*, 14 November 1995.
[49] Ibid.
[50] Wilson, E. O. *The Diversity of Life*, Cambridge Massachusetts: Harvard University Press, 1992.
[51] More disconcerting is that the increase in the rate of species extinction is faster than for other mass extinctions; these combined factors has lead a number of scientists to conclude that the planet is on the brink of another mass extinction event, brought about by human intervention upon the planet. Edward Wilson interviewed on *State of the Planet*, BBC Television, broadcast 15 November 2000.
[52] A compound of the term biological diversity.
[53] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.
[54] McLaren, Duncan, Simon Bullock and Nusrat Yousuf. *Tomorrow's World*, London: Earthscan, 1998.
[55] This is a valid approach, as land itself can be considered a natural resource, one reason for which is the provision of habitat. Personal communication from Professor John Whitelegg, Professor of Environmental Studies, Liverpool John Moores University, 7 November 1999.
[56] Solomon, Susan. 'Progress Towards a Quantitative Understanding of Antarctic Ozone Depletion', *Nature*, Volume 347, 27 September 1990.
[57] Bowman, Kenneth P. 'Global Trends in Total Ozone', *Science*, Volume 239, 1 January 1988.
[58] Freedman, Bill. *Environmental Ecology – The Ecological Effects of Pollution*, Disturbance and Other Stresses, London: Academic Press, 1996.
[59] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit.
[60] Vale, Robert and Brenda. *Green Architecture – Design for a Sustainable Future*, Thames and Hudson, 1996.
[61] Smith, R. C. et al. 'Ozone Depletion: Ultraviolet Radiation and Phytoplankton Biology in Antarctic Waters, *Science*, Volume 255, 21 February 1992.
[62] McLaren, Duncan, Simon Bullock and Nusrat Yousuf. Op. Cit.
[63] Stanners, David and Philippe Bourdeau (ed) - Commission of the European Communities and European Environment Agency. Op. Cit., p. 526.
[64] Welburn, Alan. *Air Pollution and Climate Change: The Biological Impact*, New York: Longman Scientific & Technical, 1994.
[65] Ibid.
[66] Harrison, R. M. *Pollution: Causes, Effects and Control*, London: Royal Society of Chemistry, 1990.
[67] Refer to Annexe 6.0, Completed Validation Questionnaires, in volume 3.

8.0 Interrelationships Between the Criteria of the Tool

[1] Sessions, George (ed). *Deep Ecology for the 21st Century*, London: Shambhala, 1995.
[2] Cole, Raymond J. 'Prioritising Environmental Criteria in Building Design and Assessment,' in Brandon, P. S., P. L. Lombardi and V. Bentivegna. *Evaluation of the Built Environment for Sustainability*, E & F N Spon, 1997, p. 198.
[3] Smith, Maf, John Whitelegg and Nick Williams. *Greening the Built Environment*, London: Earthscan, 1998.

[4] Cole, Raymond. 'Emerging Trends in Building Environmental Assessment Methods,' *Building Research and Information*, January/February 1998.
[5] Refer to Annexe 3.19, Lifecycle Cost.
[6] Refer to Annexe 3.37, Water Consumption: Inhabitation.
[7] Although the data for the ratio of fuels used in the production of different building materials and components does exist, it is held on a confidential database belonging to the Building Research Establishment. Therefore, the proportion of fuels is assumed to be equal between electricity, gas and petroleum. Personal communication: Jane Anderson, Consultant, Centre for Sustainable Construction, Building Research Establishment, 13 January 2000.
[8] 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.
[9] Refer to Annexe 3.15, Energy Consumption: On Site Construction Processes.
[10] The same presumption of equal ratio of fuel types is made because the fuel consumption breakdowns for different materials, although they exist, could not be determined, as they are confidential to the Building Research Establishment.
[11] This is based upon an equal consumption of electricity, gas and petroleum, with one third of the energy multiplied by the respective emission factor.
[12] Atomic mass of carbon = 12; atomic mass of carbon dioxide = 12 + 16 + 16 = 44; 44 / 12 = 3.67. Serway, Raymond A. *Physics For Scientists & Engineers*, London: Saunders College Publishing, 1990.
[13] Refer to Annexe 3.1, Carbon Dioxide Emissions: Inhabitation, in volume 3.
[14] Refer to Annexe 3.37, Water Consumption: Inhabitation, in volume 3.
[15] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.
[16] This assumption is based upon the data that was available. More detailed further research may reveal that the ratio of fuel types varies between pre site and on site energy consumption, such as an increase in petroleum. This could be accounted for in a similar manner to which fuel type variations are accounted for in the link between Energy Consumption: Inhabitation and Pollution: Energy Consumption during Inhabitation.

9.0 The Design of the Tool

[1] Chartered Institution of Building Services Engineers. *CIBSE Guide – Volume A: Design Data*, London: CIBSE, 1986.
[2] Please refer to Annexe 3.16, Energy Consumption: Inhabitation, in volume 3.
[3] The use of the SAP methodology in environmental assessment has a precedent; it is used by the Building Research Establishment for the calculation of CO_2 emissions in the *EcoHomes* assessment.
[4] Personal communication, Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.
[5] The air tightness of the dwelling is a design value, as it will be dependent upon the method and quality of construction, and therefore cannot be measured until the dwelling is complete.
[6] 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.
[7] Personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.
[8] 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.

[9] 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 demonstrates that each is appropriate as the other in terms of accuracy.
[10] 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.
[11] Refer to Annexe 3.37, Water Consumption: Inhabitation, in volume 3.
[12] BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, October 1998. This value is derived from a design for an autonomous dwelling with rainwater storage of 25,000 litres, designed for 4 people. The daily consumption was determined on the basis of the water saving appliances specified for the dwelling, such as composting toilet and low flow rate fittings.
[13] Serway, Raymond A. *Physics For Scientists & Engineers*, London: Saunders College Publishing, 1990.
[14] As the mass of 1 litre of water is one kg, no conversion factor is needed to translate between the heat capacity per kg and per litre.
[15] It is assumed that water is stored in a header tank and is at the same temperature as the dwelling, say 19 °C, and that the water is heated to 55 °C; if the difference in temperature is otherwise, the value can be adjusted accordingly. For example, if the header tank is outside the insulated space, if it is in an attic space where the insulation is laid over the ceiling, the mean temperature difference will be between 6 and 55 °C, and therefore 49 °C.
[16] BRECSU. 'Building A Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, October 1998.
[17] Sources for this data are based both on collated data and Brenda and Robert Vale. *The New Autonomous House – Design and Planning for Self-Sufficiency*, London: Thames and Hudson, 2000.
[18] 365.25 is used to convert the consumption into an annual value, accounting for leap years.
[19] As with other values, the consumption may vary if the appliance is used intermittently, for example a television or computer, rather than constantly, for example a fridge, depending upon how long the appliance is used for. This value is based upon a 28" Bang & Olufsen MS6000 used for 5 hours each day.
[20] This assumption is based on lights being used between 18:00 and 0:00 hours. Precedents for these values are contained in Brenda and Robert Vale. Op. Cit. This constant could be varied if the value is anticipated to be different.
[21] This assumption has precedent in Brenda and Robert Vale. Op. Cit.
[22] This value is based on a seated male at rest, but would increase with activity. CIBSE. *CIBSE Guide Volume A*, London: Chartered Institution of Building Services Engineers, 1986.
[23] for example, when sleeping this value may be as low as 72 watts, when sitting 99 watts, undertaking light activity, such as cooking, be up to 140 watts, and medium activity, such as housework, 200 watts.
[24] Brenda and Robert Vale. Op. Cit.
[25] Even the gains from pets could be included, with the typical dog contributing 53 watts of heat, cat 15 watts, rabbit 11 watts, and hamster 2 watts CIBSE. Op. Cit.
[26] An introspective lifestyle prevalent in suburban housing, linked to the increasing numbers of divorced single males isolated from sources of social interaction, has been attributed to causing an increase in suicide rates in this section of the population.
[27] This is based on 12 hours per day for 6 days (say 19:00 to 07:00) and 18 hours for 1 day, or 54 percent of the year. This provides a base value that can be varied if the occupancy period is considered to be different. This may be the case for different dwelling types, such as housing for the elderly or flats in hostels.
[28] 1 kWh = 3.6 MJ
[29] The calculation is based on measurements from a horizontal panel. It is considered that the value will vary little for angled panels, and those varying from a due south orientation so long as they are facing between south east and south west, in comparison to other variables, such as the efficiency of the specific panel. Personal communication, Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.
[30] CIBSE. Op. Cit. The actual variations are: zero for horizontal planes, 8 percent for planes at 30 and 45 degrees (0.11 $kWh.m^{-2}$), 10 percent for planes at 60 degrees (0.13 $kWh.m^{-2}$), and 11 percent for vertical planes (0.11 $kWh.m^{-2}$).

[31] CIBSE. Op. Cit. The actual variations are: 2 percent for south, southeast and southwest facing planes at 30 degrees (0.03 $kWh.m^{-2}$), 4 percent for south facing planes at 60 degrees (0.06 $kWh.m^{-2}$), and 7 percent for southeast and southwest facing planes at 60 degrees (0.09 $kWh.m^{-2}$).
[32] Roaf, Dr Susan. Lecturing at 'Sustainability in Building Design' seminar, University College, Chester, on 18 August 1999.
[33] The energy generation by wind turbines is determined through a calculation method used by the Centre for Alternative Technology, Machynlleth; personal communication November 1995.
[34] Shouler, M. C. and J. Hall. *Water Conservation*, Building Research Establishment, November 1998. This constant, of 0.33, is based on the level of CO_2 emissions arising as a consequence of the energy used to supply the dwelling with potable mains water, which is 0.33 $kgCO_2.a^{-1}$ per litre per day. Please refer to Annexe 3.37, Water Consumption: Inhabitation, in Volume 3.
[35] Wackernagel, M. and W. Rees. *Our Ecological Footprint*, New Society Publishers, 1996. The most effective assimilators of CO_2 in terms of greens pace, which are forests, accumulate 1.8 tonnes of carbon per hectare. 1.8 tonnes of carbon per hectare is the equivalent of 0.18 $kgC.m^{-2}$. From the relative atomic mass, 1 kgC is the equivalent of 0.66 $kgCO_2$. Therefore, the assimilation potential for green space is 0.66 $kgCO_2.m^{-2}$.
[36] These are given as tabulated data for each fuel type that the dwelling is likely to consume. The are derived from figures from the National Atmospheric Emissions Inventory in, Howard, Nigel, Suzy Edwards and Jane Anderson. *Methodology for Environmental Profiles of Construction Materials, Components and Buildings*, London: Construction Research Communications Ltd., 1999. The values are adjusted to account for the upstream and combustion emission factors, and the relative primary to delivered efficiency ratios. The worksheet procedure itself will take account of the relative efficiencies of the heating systems. For a breakdown of these emission factors, please refer to Annexe 3.23, Pollution: Energy Consumption during Inhabitation.
[37] The life span of the materials will be based on data in the Research Steering Group of the Building Surveyors Division and the Building Research Establishment's *Life Expectancies of Building Components*, Royal Institute of Chartered Surveyors, August 1992.
[38] Personal communication with Building Research Establishment's Centre for Sustainable Construction, 22 March 2000.
[39] Smith et al. use the total mass of building materials to compare the embodied energy in a standard and a low energy dwelling; Smith, Matthew, John Whitelegg and Nick Williams. 'Life Cycle Analysis of Housing', *Housing Studies*, Volume 12, Number 2, 1997. Fay et al. and Treloar et al. also both adopt the methodology of quantifying the building materials in the dwelling, and converting this value, here in terms of volume, into the total embodied energy through standard values of embodied energy; Fay, Roger, Graham Treloar and Usha Iyer-Raniga. 'Life Cycle Energy Analysis of Buildings: A Case Study', *Building Research & Information*, Volume 28, Number 1, 2000, and Treloar, G., R. Fay, P. E. D. Love and U. Iyer-Rangia. ' Analysing the Life Cycle Energy of an Australian Residential Building and its Householders', *Building Research & Information*, Volume 28, Number 3, 2000.
[40] Personal communication: Jane Anderson, Consultant, Centre for Sustainable Construction, Building Research Establishment, 13 January 2000.
[41] Personal communication, Mr J. Bullen, Technical Sales, Isothane, 8 December 1999.
[42] Personal communication, Mr G. W. Ball, British Rigid Urethane Foam Manufacturers' Association, 25 April 2000.
[43] These steps were considered to be important, as they create an absolute, rather than relative, comparison between six of the eleven most significant criteria that are being assessed by the tool.
[44] 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.

10.0 The 'Urban House in Paradise Assessment' Tool

[1] In the SAP worksheet, the constant 0.5 is used in the event that step 26 is less than 1. This is to ensure that the minimum ventilation rate used in the assessment is 0.5 $ac.h^{-1}$; if the envelope is very airtight in a naturally ventilated dwelling, then it is assumed that the inhabitants will periodically open windows to achieve the desired influx of fresh air; personal communication with Dr Brian Anderson,

BRECSU, Building Research Establishment, 7 August 2000. This constant's value has been revised to 0.45 $ac.h^{-1}$ following the analysis in the Quality of the Internal Environment: Ventilation and Air Tightness benchmark for the minimum ventilation rate of the dwelling.

[2] The heat loss from the ventilation of the dwelling is calculated by multiplying the volume of the dwelling by the effective air change rate, to determine how much warm air is being removed from the dwelling to be replaced by cooler fresh air. This is multiplied by the specific heat capacity of air, hence the constant 0.33 $kW.m^{-3}.K^{-1}$.

[3] 4,186 $J.kg^{-1}.K^{-1}$ is the specific heat capacity of water. 365.25 converts the consumption into an annual value, accounting for leap years.

[4] In the SAP assessment, the distribution losses, where applicable, are 17.7 percent of the hot water energy requirement, hence the constant.

[5] The metabolic gains per occupant are 115 W. The constant 90 is to account for the occupancy of the dwelling; this assumes that it is occupied for 90 hours in each week, 54 percent of the total: 6 hours per day for 6 days and 18 hours per day for 1 day. This value can be varied in respect of the anticipated occupancy period. The constant 8,760 is the number of hours in a year.

[6] The constant 6 is used on the basis of an assumed that each bulb will be used on average for 6 hours each day. The calculation also assumes one bulb per inhabitant. The values can be adjusted if necessary.

[7] It is assumed that 90 percent of the energy used by appliances is incidental gain in the dwelling. The constant 1,000 in this and the next step convert the consumption form $kWh.a^{-1}$ into $Wh.a^{-1}$, and the constant 8,760 converts the value into watts, to be compatible with the SAP assessment.

[8] It is assumed that 100 percent of the energy used in cooking is incidental gain in the dwelling.

[9] The constant 31.71 is to convert the value from step 145, which is in $GJ.a^{-1}$ into watts to be compatible with the other values in the internal gains calculation. 1 $GJ.a^{-1}$ is the equivalent of 277.78 $kWh.a^{-1}$; dividing this by the number of hours in one year, 8760, and multiplying by 1000 gives the value in watts. Personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.

[10] In the SAP worksheet the constant 0.000 08604 is used as a conversion factor to convert the outcome of this product into $GJ.a^{-1}$, derived from the number of hours in a year divided by 10^9; personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000. Because the tool is in units of $kWh.a^{-1}$, 0.000 08604 is multiplied by 277.78 to convert from $GJ.a^{-1}$ to $kWh.a^{-1}$, to derive the constant 0.0240.

[11] The constant 277.78 is used to convert from $GJ.a^{-1}$ to $kWh.a^{-1}$.

[12] The constant 6 is used on the basis of an assumed that each bulb will be used on average for 6 hours each day. The calculation also assumes one bulb per inhabitant. The values can be adjusted if necessary.

[13] The constant of 1.3 is the typical solar radiation level in the United Kingdom taking into account the typical efficiency of solar water panels, derived from measured analysis; personal communication with Dr Brian Anderson, BRECSU, Building Research Establishment, 7 August 2000.

[14] The constant 277.78 is used to convert from $GJ.a^{-1}$ to $kWh.a^{-1}$.

[15] The software chosen for this is Microsoft Exel, Microsoft Office 98 - Macintosh Edition, Microsoft Corporation.

11.0 Validation and Testing

[1] A copy of the assessment is located at the end of this chapter.

[2] Refer to Chapter 4.0, Benchmarking the 'Urban House in Paradise', and Annexe 3.0, Benchmark Analysis of the Criteria, in volume 3.

[3] For example the emission factor for electricity is more than double that of natural gas, 0.59 $kgCO_2.kWh^{-1}$ in comparison to 0.19 $kgCO_2.kWh^{-1}$.

[4] There are a number of timber frame ultra-low-energy dwellings, including the Low-Energy House B, in Denmark, the Waterloo Region Green Home in Canada, the Zero-Energy Dwelling in Switzerland, and the Duncan House in Canada. BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, HMSO, February 1996.

[5] In response to the latter, *GIR 53* provides data that was used to provide different scenarios of the consumption various degrees of efficiency for lights and appliances, from the typical dwelling, to zero CO_2, zero heating and autonomous standards. These were also used to refine the tables in the tool, if

the assessment is to be based on floor area. The values provided in *GIR 53* are for a whole dwelling. These can be converted into percentages of each other, thereby determining the percentage reduction for each of the more efficient scenarios. These reductions can then be applied to the values in the table derived from BREDEM data which gives the energy consumption as related to the total floor area of a given dwelling to give four different efficiency scenarios for the designer to adopt.

[6] For example 'Band A' appliances in the standard European grading system.

[7] Refer to cost summary in analysis of Drawn Study Seven and Eight, in volume 2.

[8] The extensive use of prefabrication in Holland has lead to construction cost reductions of up to 15 percent over comparable buildings in the United Kingdom. Moerkerken, Han. '... and how much does this cost?', *Building*, 8 September 2000. This would reduce the construction cost of the drawn study to 9.82 £.m^{-2}.a^{-1}.

[9] Refer to Lifecycle Cost analysis in Benchmark Analysis of Drawn Studies Six, Seven and Eight by Manual Calculation in volume 2.

[10] A similar construction technology was used to that proposed for the drawn study, external walls were constructed in timber frame with 300mm insulation, finished externally in timber cladding; floors were suspended timber; windows were double glazed in timber frames. BRECSU. Op. Cit.

[11] The dwelling was constructed with a timber frame wall, 300mm of insulation, and finished in timber cladding; floors were suspended timber and windows double glazed in wood frames; a polyethylene vapour barrier was also specified. Ibid.

[12] Derived from Vale, Brenda and Robert. *The Autonomous House – Design and Planning for Self-Sufficiency*, Thames and Hudson, London, 1975.

[13] Szokolay, S. *Environmental Science Handbook*, London: The Construction Press, 1980.

[14] The values for specific heat capacity are taken from Serway, Raymond A. *Physics For Scientists & Engineers*, London: Saunders College Publishing, 1990; and Vale, Brenda and Robert. Op. Cit.

[15] In their comparative analysis of hypothetical low mass and high mass rooms, they note that the energy embodied in transporting materials to site will, all else being equal, be 23 times higher for the high mass room. Vale, Brenda and Robert. Op. Cit.

[16] Breuer D. *Energy and Comfort Performance Monitoring of Passive Solar, Energy Efficient New Zealand Residences – Report Number 171*, Wellington: New Zealand Energy Research and Development Committee, 1988; in Vale, Brenda and Robert. Op. Cit.

[17] Ian Wroot 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. Geoffrey Brundrett 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.

[18] The interview with Brundrett was conducted on 18 September 2000; the interview with Wroot was conducted on 21 September 2000.

[19] Personal communication with Dr Brian Anderson, BRECSU, 7 August 2000.

[20] Refer to Case Study Two, 5.2.

[21] Vale, Robert and Brenda. Op. Cit.

[22] The lowest measured monthly average dry-bulb air temperature in the dwelling, in February 1995, was 15 °C which was in the bedrooms; in the living room this was 17.5 °C in March 1996. Ibid.

[23] Research demonstrates that since the end of the 1940s, average internal winter temperatures have been rising, from 14.3 to 18.6 °C in the 1980s. Lowe, R., J. Chapman and R. Everett, 'The Pennyland Project', *ETSU Report E5A/CON/1046/174/040*, Oxford: Energy Technology Support Unit, 1985. The reasons for this could be manifold, including the increase in the number of dwellings with central heating installations and the tendency to wear fewer layers of clothing.

[24] Interview with Brundrett, 18 September 2000.

[25] The basic information on typical appliance consumption on the basis of floor area was determined by translating data from the BREDEM assessment; however, to take account of increased efficiency in appliance specification, these values were extrapolated through the scenarios of zero CO_2, zero heating and autonomous dwellings in *GIR 53*, as a part of the research. The specific values of appliances is based on empirical studies also conducted as a part of the research; this allows the designer to more accurately predict the consumption of the dwelling on the basis of the appliances that are likely to be included, and to account for the specific use of low energy consumption appliances.

[26] This took place at the offices of the Sustainable Construction Unit of the Building Research Establishment on 16 August 2000.

12.0 Conclusions

[1] When environmental sustainability was considered as reduction in contribution to global warming, reduction in pollution emissions, reduction in natural resource consumption including habitat destruction, and reduction in ozone depleting emissions.
[2] Wackernagel, M. and W. Rees. *Our Ecological Footprint: Reducing Human Impact on the Earth*, Canada: New Society Publishers, 1995.
[3] DETR website, 23 August 2000: www.wildlife-countryside.detr.gov.uk/vbc/ecofact2/index.htm
[4] Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames and Hudson limited, 2000.
[5] The methodology used to determine the embodied CO_2 benchmark on the basis of embodied energy is contained within the benchmark analysis of the Ecological Weight: Embodied CO_2, refer to Annexe 3.14, in volume 3.
[6] These values are derived from the most efficient dwelling proposed in BRECSU. 'Building a Sustainable Future – Homes for an Autonomous Community', *General Information Report Number 53*, London: HMSO, October 1998.
[7] Lund, P. 'Optimum Solar House: Interplay Between Solar Aperture and Energy Storage', *International Solar Energy Society World Conference*, Helsinki: University of Technology, 1993; in Vale, Brenda and Robert. Op. Cit.
[8] Brenda and Robert. Op. Cit.
[9] This dwelling was appraised in the second case study, refer to 5.2.
[10] The 'urban house in paradise' benchmark could be refined in line with the suggested methodology using the assessment tool.
[11] Department of the Environment and the Welsh Office. *The Building Regulations – Approved Document E: Resistance to the Passage of Sound*, HMSO, 1992.
[12] Pearson, Andy. 'Noisy Neighbour Rules Spell Trouble for House Builders', *Building*, 27 October 2000.
[13] 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.
[14] The focus groups were: Government policy makers and researchers, construction professionals, construction material producers and manufacturers, property and institutional investors, environmental activists and lobbyists, local authority policy makers and planners, and academics and researchers.
[15] Cole, Raymond J. 'Emerging Trends in Building Environmental Assessment', *Building Research & Information*, Number 26 Issue 1, 1998.
[16] Scott, Geoffrey. *The Architecture of Humanism*, Methuen, 1961, p. 3.
[17] For example, such as scenario four on drawing 2 of 3 in Drawn Study Six, of 502 $p.ha^{-1}$.
[18] 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.
[19] The reduction from 50.4 to 10.7 $kgCO2.m^{-2}.a^{-1}$ is multiplied by the area of a typical 3 bedroom semi-detached dwelling, to give an annual reduction per dwelling of 3.3745 tonnes. Multiplied by 3.8 million dwelling equates to an annual reduction of 12,823,100 tonnes.
[20] Department of the Environment, Transport and the Regions. *Climate Change – Draft UK Programme*, London: HMSO, 2000.
[21] Friends of the Earth. *Apocalypse Now*, London: Friends of the Earth, October 2000.
[22] The reduction of 12.8 million tonnes is 7.6 percent of the total CO_2 emissions arising from the United Kingdom in 1990, of 167.5 million tonnes. Department of the Environment, Transport and the Regions. *Climate Change – Draft UK Programme.*
[23] Intergovernmental Panel on Climate Change. T*he IPCC Scientific Assessment*, Cambridge: Cambridge University Press, 1996; and Weizsacker, Ernst von, Amory B. Lovins and L Hunter Lovins. Op. Cit
[24] The second cost option prepared by Davis Langdon Everest, excluding the basement, is used here as it still achieves the Energy Consumption: Inhabitation, Energy Generation: Inhabitation and CO_2

Emissions: Inhabitation benchmarks used in this example; this is used in comparison to the option based on the dwelling built using traditional construction methods.

[25] Department of the Environment, Transport and the Regions. *Our Towns and Cities: The Future – Delivering an Urban Renaissance*, London: HMSO, November 2000.

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