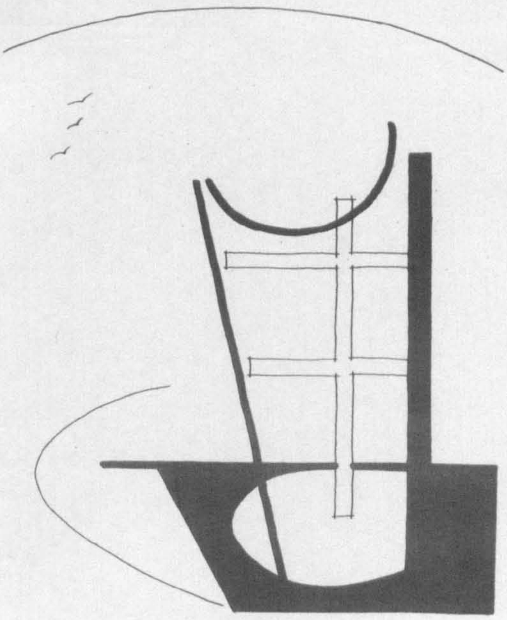
PROCURING THE URBAN HOUSE IN PARADISE

Charles Roy Smith



Volume 2 - Drawn Studies

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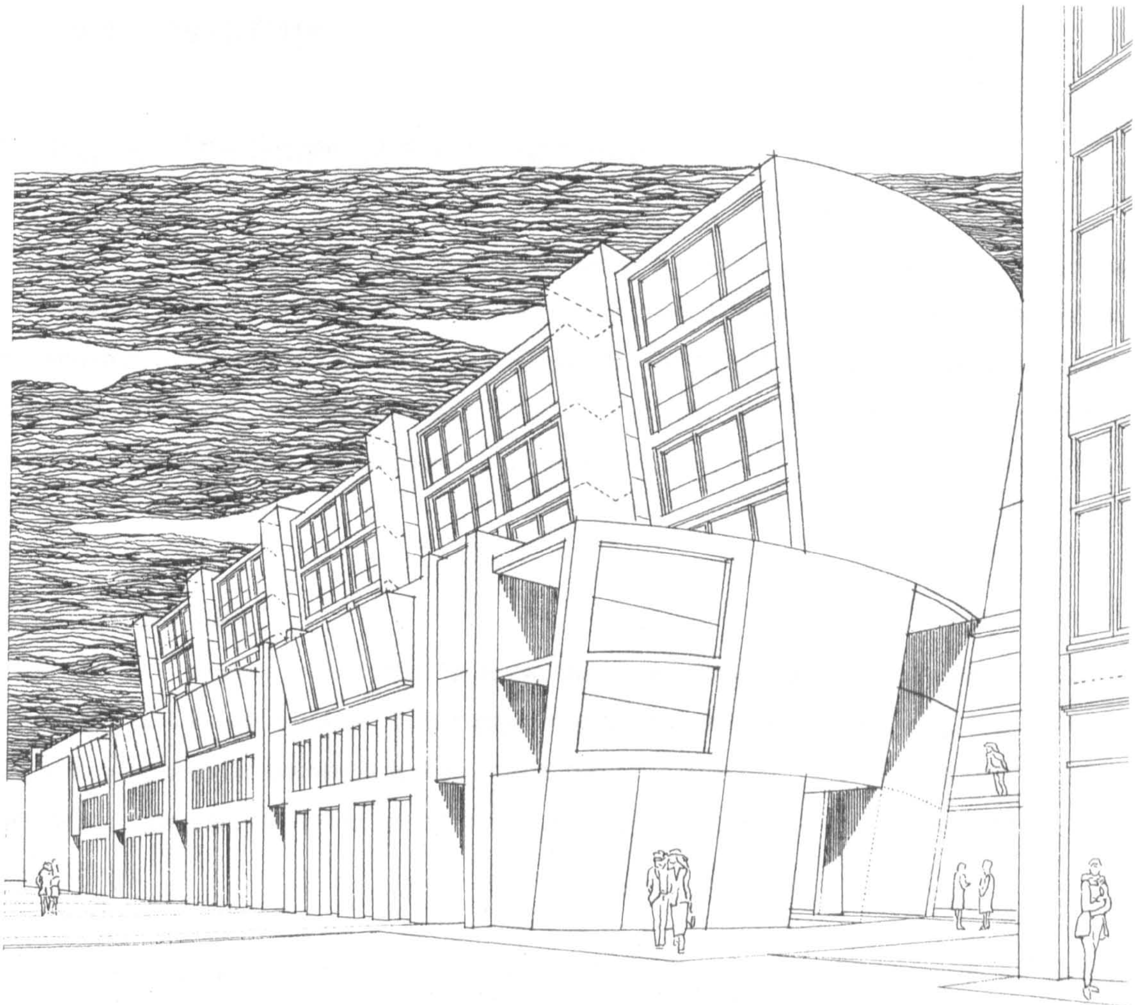

Glasgow: Scale of the Urban Block

Drawn Study One

Glasgow: The Scale of the Urban Block

The first two Drawn Studies were combined within a response to the brief issued for the Innovative Brick Housing Competition, sponsored by the Brick Development Association. An ambition of the competition was to promote the design of innovative residential projects that can contribute to the identified growth and needs of future households, of which changing demographics is a significant contributory factor.

Site and Context

The site is situated within the historic Merchant City area of Glasgow, in close proximity to the city centre. Two listed buildings adjoin the 0.3 Ha site, the majority of which is vacant brownfield land with the exception of one five storey existing building. The vertical scale of the buildings surrounding the site varies from four to six storeys.

Of the six potential sites offered within the brief, one in the Merchant City area of Glasgow was selected. There were two principal reasons behind this. Firstly it was a brownfield site, which was considered crucial in a thesis predicated toward the sustainability of dwellings; land, and in particular greenfield land, is a natural resource, not least through the provision of habitat and, therefore, contribution to species biodiversity. Secondly, the site was the closest in proximity to a city centre and had the greatest scale of fabric around it; therefore it was considered to be the most 'urban' of the six, which was considered significant in a thesis predicated toward urban dwellings.

The site is located within the historic Merchant City area of Glasgow, less than half of a kilometre south-east of the city centre. The fabric of the area originally stems from the mercantile and residential origins of the late 18^{th} and 19^{th} century; substantial redevelopment in the recent past has created a diverse range of mixed function buildings and projects. The vertical scale of the context surrounding the site varies from four to six storeys. Bounded by Wilson Street, Brunswick Street, Hutcheson Street and Trongate, the principal frontage, the site area is approximately 0.3 hectares. Two listed buildings adjoin the site, to the north a six-storey red sandstone office building and to the south a four-storey building comprised of retail units. One existing building is within the site boundary, a five-storey office building occupying the west edge of the site, stretching toward Trongate.

House on House

Two principal themes underpin the design conceptually: 'house on house' and 'house in house'. 'House on house' was manifested in the reinterpretation of the Merchant House and the Town House; these two traditional forms of housing in Glasgow have historically provided long-lasting adaptable space. The design explored the way in which these two types of house could be integrated into an urban block at a scale appropriate to the site.

The project sought to achieve a synthesis between the design of a visually dignified urban block and an innovative means of technological procurement and detailed design; also, to investigate ways in which rational, adaptable standardised building systems could be applied to a development at the scale of the urban block. The urban design established public integration through courtyards, and clearly defined territories for residents.

Innovation in terms of the urbanity of the project lay primarily in the way in which the accommodation was organised vertically and horizontally. This led to two principal themes, house-on-house and house-in-house, as the conceptual basis underpinning the design. The Merchant House and the Town House are two traditional forms of housing in Glasgow, which historically have provided long-lasting adaptable space; longevity was considered significant in maximising the resources embodied within the structure. It was the extensive contribution of the 19th century to the development of these types, and in particular of the architect Alexander Thomson, which the project refers to. The design explored the way in which two types of house, on the street frontage the 'Merchant House' and above, as an inhabited roof, the 'Town House', can be integrated into an urban block at a scale appropriate to the site. In this way, integrated, but differentiated, space was proposed for retail and commercial use and for dwelling. The 'Town Houses' are stepped back in cross-section from the edges of the site to reduce the visual impact of the increase in mean storey height from street level.

House in House

The ability of spaces to adapt to the unforeseeable changes in patterns of inhabitation was perceived as a prototypical urban problem. The proportion of the overall urban block is structured from five pairs of vertical ribs, or 'supports'. These provide the structure and servicing to both Houses, leaving clear spans between to maximise potential flexibility of use and potential adaptability within the 'shells'.

The ability of spaces to adapt to the unforeseeable changes in patterns of inhabitation, speaking both singularly of a particular dwelling, and the plurality of the culture of changing habitation patterns and rituals, is increasingly becoming an area of innovation in housing design. It is a prototypical urban problem. Adaptability can extend beyond the individual dwelling, to become an adaptable block, where individual units can be absorbed to create larger dwellings or premises. John Habraken notably developed the latter philosophy of adaptability in the 1960s.[1] Habraken's ambition was to end the monotony of mass housing through the provision of housing as 'supports and shells'. The support structure enabled dwellings to be built within the structure independently of each other.

> A support structure is a construction which allows the provision of dwellings which can be built, altered and taken down, independently of the others.[2]

The initial exploration of the criterion of adaptability as a way in which to define the 'urban house in paradise' began in Drawn Study One and Two.

Urban Integration and Composition

The principal elements of the overall composition are the five pairs of support ribs, the two courtyards at each end of the block, and the axis, a re-interpretation of the Glasgow 'Lane', that pierces the ribs linking the courtyards. The transition between public space to semi-public space to semi-private space articulates movement toward the private realm of the dwelling.

The following elements combine to create the overall architectural composition. The proportion of the overall urban block is structured by five pairs of vertical ribs, or 'supports', that rise through and support both the 'Merchant Houses and 'Town Houses'. These ribs

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[1] Habraken , John N. (translated into English by B. Valkenburg). *Supports: An Alternative To Mass Housing*, London: The Architectural Press, 1972.
[2] Ibid., p.59.

would provide the structure and servicing to both Houses, leaving clear spans between to maximise potential flexibility of use and potential adaptability within the 'shells'. Retail and commercial premises are located on three floors on the street edges of Brunswick Street and Hutcheson Street. The commercial spaces, which are located over the retail spaces, can be accessed from the street frontage via the ribs.

Two courtyards are located north and south, providing semi-public space that mediates between the two existing buildings to be retained and the new development. The buildings that wrap the southern courtyard front Brunswick Street and Trongate, the most public face of the project, are of a scale comparable to that of the adjacent existing building; the block itself rises behind, stepped back to minimise visual intrusion from the street.

A north-south axis linking the courtyards bisects the site, piercing each rib; it provides a glimpse of the activities within the block to the people passing along Trongate. This route is an interpretation of the Glasgow 'Lane', as opposed to an arcade, and is linked visually to the commerce on either site. It is a covered space, naturally lit from above, accessible from both courtyards; a semi-private space for use by the people who inhabit the dwellings above both as access to their dwellings and as an incidental meeting space.

The transition between the public space of the city and the private space of the dwelling was explored within the urban block. The sequence and hierarchy of thresholds, from the public space of the street, through the semi-public space of the courtyards to the horizontal and vertical semi-private space of the lane and ribs, articulates movement toward the private realm of the urban dwelling.

Car parking space, in accordance with the provision demanded by Glasgow City Council, is located within the basement, accessed via a ramp at the northern end of the site. This removes the accommodation of an unsustainable object from the street, the inclusion of which was demanded by the brief.

Diversity and Density

The initial exploration of density and programmatic diversity as criteria of the 'urban house in paradise' began in Drawn Study 1. The potential adaptability of both the 'Merchant House' and 'Town House' made these criteria variable, even within the fixed structure of the urban block.

Both the initial exploration of the benchmark of density and the creation and evolution of programmatic diversity as a criterion with which to define the 'urban house in paradise' began in Drawn Study 1. Since the 1960s there has been little work undertaken in the United Kingdom on adaptable building in cities. Recent re-kindled interest and relevant work in Europe from the last thirty years provide an important resource upon which the project buildt. The 8 Merchant Houses can be divided into diverse sizes of space; the number of businesses that could be accommodated ranges from 8 to 48. The impact on this flexibility can be seen in the range of the Diversity benchmark, between 48 and 150 programmes per hectare.

Within the adaptable structure of the 'Town House' the number of households that can be accommodated ranges from 16 to 64. This creates a range of potential net residential densities, with a mean value of 350 people per hectare. The area of land used to determine this value extended to the full expanse of the site. Whilst net density excludes the land used by functions other than dwelling, because the other functions and open spaces are below the 'Town House' block it was not considered appropriate to deduct any land area. The sustainable urban density proposed by Friends of the Earth ranges from 225 to 300 people per hectare, rising to 370 people per hectare in central urban areas. The density achieved at the Glasgow site, whilst providing many other functions, is of the magnitude advocated by Friends of the Earth. Therefore, it can be established that the net density proposed by Friends of the Earth could be achieved in a four-storey block of apartment flats.

The performance of the Drawn Study in terms of the criteria of the 'urban house in paradise' can be seen in the table overleaf. As this Drawn Study was intended as an initial exploratory exercise, not all of the benchmarks have been evaluated. It was not considered relevant to evaluate the performance of a project against criteria that were not accounted for during the design process.

Criteria		Benchmarks
		Glasgow: Scale of the Urban Block
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		Assessed in Drawn Study 2
CO2 emissions: On Site Construction Processes: kgCO2.m-2		Not Assessed
Carbon intensity: kg.kWh-1		Not Assessed
Construction period: weeks per dwelling		Not Assessed
Contextual significance of site: Qualitative		Yes
Deconstruction and demolition: Recycling materials: Percent		Not Assessed
Design life span: Years		Not Assessed
Density:	quantitative: p.ha-1	mean 350
	qualitative	Yes and Yes
Diveristy: programmes.ha-1		mean 53
Domestic waste:	refuse: kg.p-1.wk-1	Not Assessed
	recycled: kg.p-1.wk-1	Not Assessed
Ecological significance of the site: Percent and qualitative		100, Yes and Yes
Ecological weight: embodied energy: kWh.m-2		Not Assessed
Ecological weight: CO2 emissions: kgCO2.m-2		Not Assessed
Energy consumption: construction: kWh.m-2		Not Assessed
Energy consumption: inhabitation: kWh.m-2.a-1		Not Assessed
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study 2
Green space: Percent		0
Lifecycle cost:	Construction: £.m-2.a-1	Not Assessed
	Energy: £.m-2.a-1	Not Assessed
	Water: £.p-1.a-1	Not Assessed
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study 2
Other ecological impacts of materials: Qualitative, g.kWh-1		Not Assessed
Other greenhouse gas emissions: g.kg-1		Not Assessed
Pollution: energy consumption inhabitation: g.kWh-1		Not Assessed
Procurement strategy: Qualitative		Not Assessed
Quality of internal environment:	indoor pollution: Qualitative	Not Assessed
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 2
	ventilation: ac.h-1	Assessed in Drawn Study 2
	airtightness: ac.h-1 at 50 Pa	Not Assessed
Recycling construction waste: Percent		Not Assessed
Adaptability: Internal loadbearing walls: Internal walls		0
Space standards: Area	1 person: m2.p-1	Not Assessed
	2 persons: m2.p-1	Assessed in Drawn Study 2
	3 persons: m2.p-1	Assessed in Drawn Study 2
	4 persons: m2.p-1	Assessed in Drawn Study 2
	5 persons: m2.p-1	Not Assessed
	6 persons: m2.p-1	Not Assessed
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	8 persons: m3.p-1	Not Assessed
	9 persons: m3.p-1	Not Assessed
	10 persons: m3.p-1	Not Assessed
Thermal Performance:	Roof: W.m-2.K-1	Not Assessed
	Exposed walls: W.m-2.K-1	Not Assessed
	Ground and exposed floors: W.m-2.K-1	Not Assessed
	Windows and rooflights: W.m-2.K-1	Not Assessed
	Opaque outer doors: W.m-2.K-1	Not Assessed
Use of recycled materials: Percent		Not Assessed
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Not Assessed
Water consumption: inhabitation:	potable: l.p-1.d-1	Assessed in Drawn Study 2
	rain and grey: l.p-1.d-1	Assessed in Drawn Study 2
	total: l.p-1.d-1	Assessed in Drawn Study 2

Benchmark performance of Drawn Study 1

Drawn Study One

Site and Context

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House on House

Two principal themes underpin the design conceptually: 'house on house' and 'house in house'. 'House on house' was manifested in the reinterpretation of the Merchant House and the Town House; these two traditional forms of housing in Glasgow have historically provided long-lasting adaptable space. The design explored how these two types of house could be integrated into an urban block at a scale appropriate to the site.

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House in House

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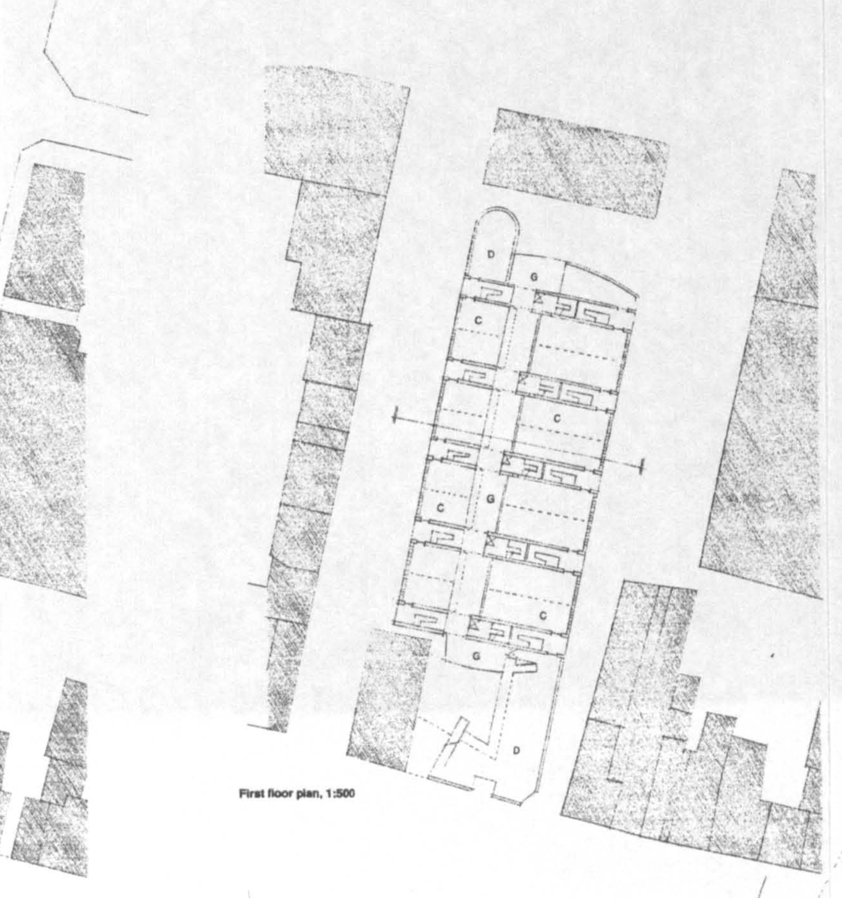
Location plan, 1:5,000

Circulation plan, 1:1,000

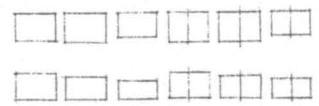
Circulation Key
A: Courtyard
B: Lane
C: Entrance from street
D: Entrance to ground level of 'Merchant House'
E: Up to upper level of 'Merchant House'
F: Up to 'Town House'
G: Through links

Ground floor plan, 1:500

Plan Key
A: Courtyard (semi-public space)
B: Lane (semi-private space)
C: Adaptable commercial space
D: Commercial space
E: Access to car parking
F: Storage
G: Void

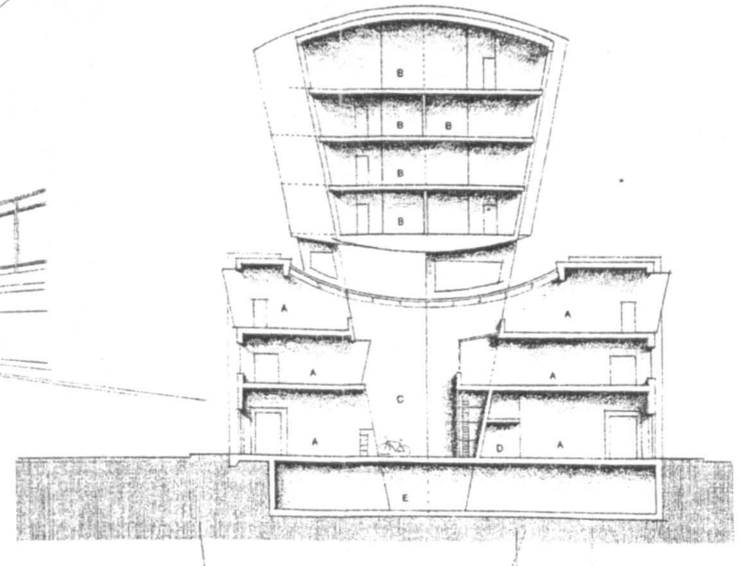


First floor plan, 1:500



Permutations of adaptability of 'Merchant House'
48 interchangeable variations

View of site from Trongate



Cross section through 'Merchant House' and 'Town House'

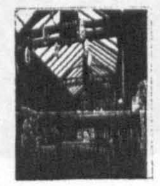
Cross Section Key
A: Adaptable commercial space
B: Adaptable residential space
C: Lane
D: Storage
E: Car parking

Exploded block elevation to Hutcheson Street, 1:500

Contextual Influences

Great Western Terrace,
Alexander Thomson, 1869

Crown Arcade, 1819



Glasgow School of Art,
C. R. Mackintosh, 1896-9

Glasgow: Scale of the Urban Block

Urban Integration and Composition

The principal elements of the overall composition are the five pairs of support ribs, the two courtyards at each end of the block, and the axis, a re-interpretation of the Glasgow 'Lane', that pierces the ribs linking the courtyards. The transition between public space to semi-public space to semi-private space articulates movement toward the private realm of the dwelling.

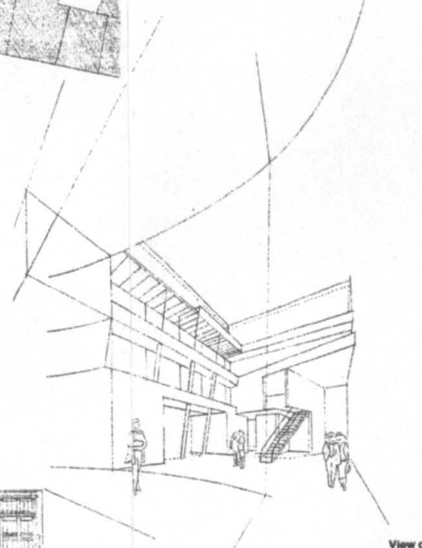
The proportion of the overall urban block is structured by five pairs of vertical ribs, or 'supports', that rise through and support both the 'Merchant Houses and 'Town Houses'. These ribs would provide the structure and servicing to both Houses, leaving clear spans between to maximise potential flexibility of use and potential adaptability within the 'shells'. Retail and commercial premises are located on three floors on the street edges; the commercial spaces are accessed from the street frontage via the ribs.

Two courtyards are located north and south, providing semi-public spaces. The buildings that wrap the southern courtyard front Brunswick Street and Trongate, are of a scale comparable to that of the adjacent existing building; the block itself rises behind, stepped back to minimise visual intrusion from the street. A north-south axis linking the courtyards bisects the site, piercing each rib; it provides a glimpse of the activities within the block to the people passing along Trongate. This route is an interpretation of the Glasgow 'Lane'. It is a covered space, naturally lit from above, accessible from both courtyards; a semi-private space for use by the people who inhabit the dwellings above. The transition between the public space of the city and the private space of the dwelling was explored within the urban block. The sequence and hierarchy of thresholds, from the public space of the street, through the semi-public space of the courtyards to the semi-private space of the lane and ribs, articulates movement to the private realm of the urban dwelling.

Diversity and Density

The initial exploration of density and programmatic diversity as criteria of the 'urban house in paradise' began in Drawn Study 1. The potential adaptability of both the 'Merchant House' and 'Town House' made these criteria variable, even within the fixed structure of the urban block.

Since the 1960s there has been little work undertaken in the United Kingdom on adaptable building in cities. Recent re-kindled interest and relevant work in Europe from the last thirty years provide an important resource upon which the project buildt. The 8 Merchant Houses can be divided into diverse sizes of space; the number of businesses that could be accommodated ranges from 8 to 48. The impact on this flexibility can be seen in the range of the Diversity benchmark, between 48 and 150 programmes per hectare. Within the adaptable structure of the 'Town House' the number of households that can be accommodated ranges from 16 to 64. This creates a range of potential net residential densities, with a mean value of 350 p.ha^{-1}. The sustainable urban density proposed by Friends of the Earth ranges from 225 to 300 p.ha^{-1}, rising to 370 in central urban areas. Therefore, it can be established that the net density proposed by Friends of the Earth could be achieved in a four-storey block of apartment flats.



View of courtyard to Trongate

Criteria		Benchmarks
		Glasgow: Scale of the Urban Block
CO2 emissions: inhabitation: kgCO2.m-2.a-1		Assessed in Drawn Study 2
CO2 emissions: On Site Construction Processes: kgCO2.m-2		Not Assessed
Carbon intensity: kg.kWh-1		Not Assessed
Construction period: weeks per dwelling		Not Assessed
Contextual significance of site: Qualitative		Yes
Deconstruction and demolition: Recycling materials: Percent		Not Assessed
Design life span: Years		Not Assessed
Density	quantitative: p.ha-1	mean 350
	qualitative	Yes and Yes
Diversity: programmes.ha-1		mean [illegible]
Domestic waste	refuse: kg.p-1.wk-1	Not Assessed
	recycled: kg.p-1.wk-1	Not Assessed
Ecological significance of the site: Percent and qualitative		100, Yes and Yes
Ecological weight: embodied energy: kWh.m-2		Not Assessed
Ecological weight: CO2 emissions: kgCO2.m-2		Not Assessed
Energy consumption: construction: kWh.m-2		Not Assessed
Energy consumption: inhabitation: kWh.m-2.a-1		Not Assessed
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study 2
Green space: Percent		0
Lifecycle cost	Construction: £.m-2.a-1	Not Assessed
	Energy: £.m-2.a-1	Not Assessed
	Water: £.p-1.a-1	Not Assessed
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study 2
Other ecological impacts of materials: Qualitative, g.kWh-1		Not Assessed
Other greenhouse gas emissions: g.kg-1		Not Assessed
Pollution: energy consumption inhabitation: g.kWh-1		Not Assessed
Procurement strategy: Qualitative		Not Assessed
Quality of internal environment	indoor pollution: Qualitative	Not Assessed
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 2
	ventilation: ac.h-1	Assessed in Drawn Study 2
	airtightness: ac.h-1 at 50 Pa	Not Assessed
Recycling construction waste: Percent		Not Assessed
Adaptability: internal loadbearing walls: [illegible]		0
Space standards: Area	1 person: m2.p-1	Not Assessed
	2 persons: m2.p-1	Assessed in Drawn Study 2
	3 persons: m2.p-1	Assessed in Drawn Study 2
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	8 persons: m2.p-1	Not Assessed
	9 persons: m2.p-1	Not Assessed
	10 persons: m2.p-1	Not Assessed
Space standards: Volume	1 person: m3.p-1	Not Assessed
	2 persons: m3.p-1	Assessed in Drawn Study 2
	3 persons: m3.p-1	Assessed in Drawn Study 2
	4 persons: m3.p-1	Assessed in Drawn Study 2
	5 persons: m3.p-1	Not Assessed
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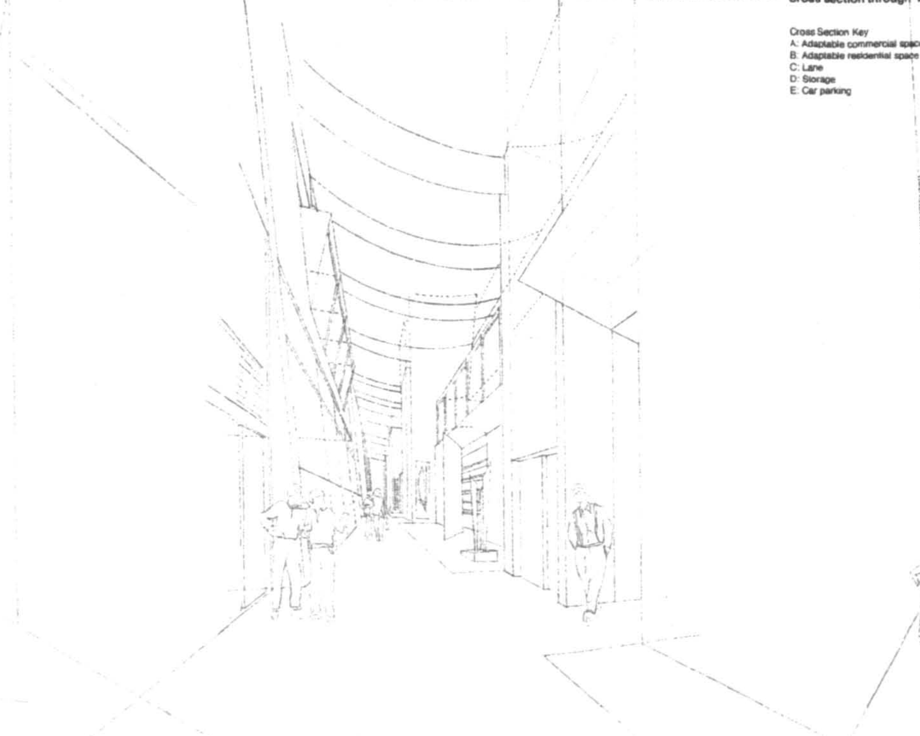
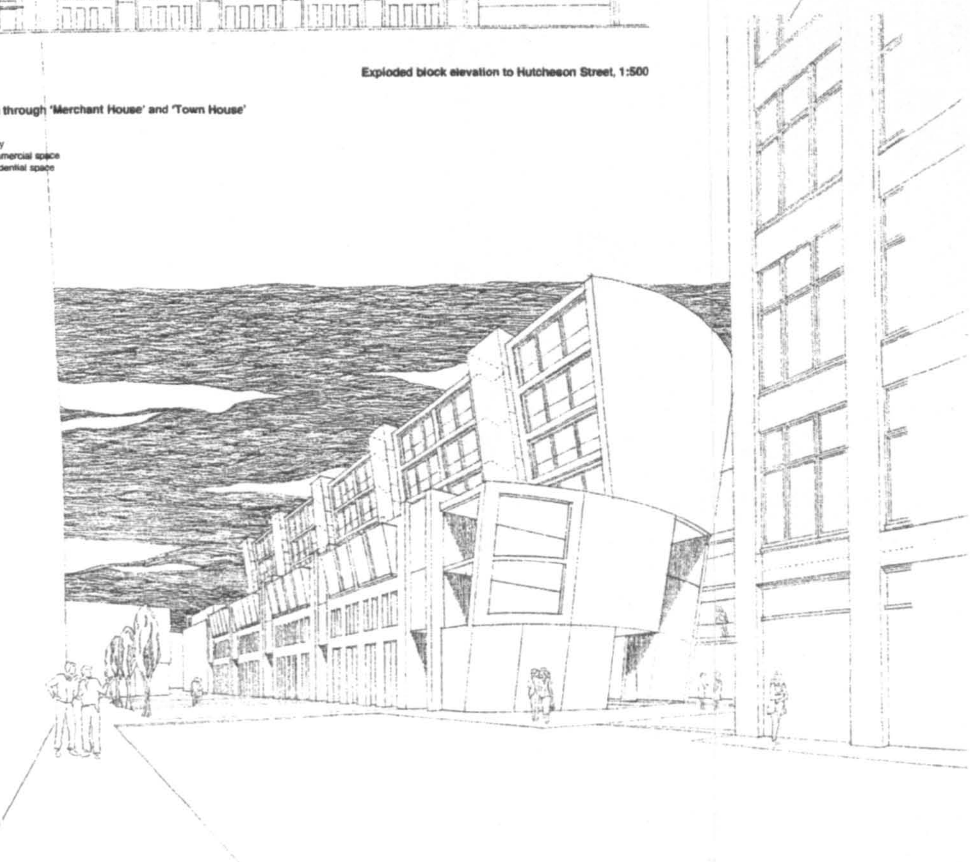
	7 persons: m3.p-1	Not Assessed
	8 persons: m3.p-1	Not Assessed
	9 persons: m3.p-1	Not Assessed
	10 persons: m3.p-1	Not Assessed
Thermal Performance	Roof: W.m-2.K-1	Not Assessed
	Exposed walls: W.m-2.K-1	Not Assessed
	Ground and exposed floors: W.m-2.K-1	Not Assessed
	Windows and rooflights: W.m-2.K-1	Not Assessed
	Opaque outer doors: W.m-2.K-1	Not Assessed
Use of recycled materials: Percent		Not Assessed
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Not Assessed
Water consumption: inhabitation	potable: l.p-1.d-1	Assessed in Drawn Study 2
	rain and grey: l.p-1.d-1	Assessed in Drawn Study 2
	total: l.p-1.d-1	Assessed in Drawn Study 2

View of site from Hutcheson Street looking south

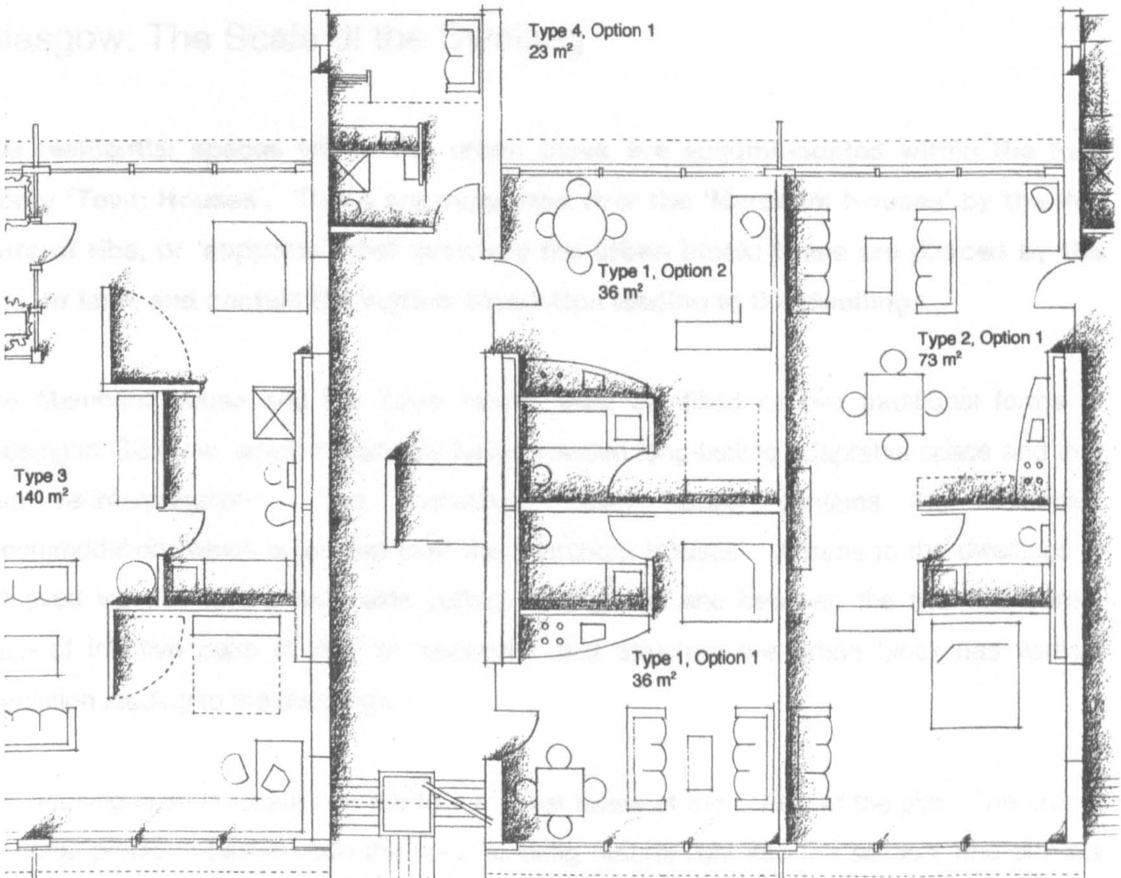


Interior of 'Lane'



View of site from Brunswick Street looking south

Drawn Study Two



Glasgow: Scale of the Dwelling

Drawn Study Two

Glasgow: The Scale of the Dwelling

The residential spaces within the urban block are accommodated within the four storey 'Town Houses'. These are supported over the 'Merchant Houses' by the five pairs of ribs, or 'supports', that structure the urban block; these are pierced by the axis, or lane, and contain the vertical circulation leading to the dwellings.

The Merchant House and the Town House were identified as two traditional forms of housing in Glasgow, which historically have provided long-lasting adaptable space and that bear re-interpretation. The conceptual 'Town House' contains the residential accommodation, which is located over the 'Merchant Houses'. Access to the dwellings is achieved via the semi-private axis cutting through the site between the two courtyards. Each of the five pairs of ribs, or 'supports', that structure the urban block has vertical circulation leading to the dwellings.

The housing itself is located on the four highest levels at the centre of the site. The cross-sectional profile is based upon the need to bring natural light into the section, and provide different dwelling sizes. The ribs that act as circulation cores to the housing are conceived of as buildings in themselves, and can accommodate rooms for students, guests and others among more itinerant groups of urban dwellers. These dwellings for transient inhabitants can be both single and double storey spaces. Each rib could provide access for between 8 and 20 dwellings.

House in House - Adaptability

'House in House' is conceived of as the exploration of the way in which different patterns of use can be accommodated. The traditional 'Japanese lunch box' provided the conceptual impetus for the resolution of the relationship between generic urbanity and personal acts of urban dwelling, leading toward the variation in permutations of accommodation that are available. The ability of the urban block to respond to changing needs demonstrates the project's ambition to reflect the changing demographic patterns in the population.

'House in House' is conceived of as the exploration of the way in which different patterns of use can be accommodated within each of the two House types proposed, in ways that leave each of the urban elements spatially coherent. The vertical ribs are structural, and carry all services, leaving the space between each rib as a shell that can house different permutations of dwelling arrangement. The traditional 'Japanese lunch box,' four standard enclosures each containing with a different filling, provided an impetus for the resolution of the relationship between generic urbanity and personal acts of urban dwelling.

A successful relationship between the generic and the personal requires a specific form of adaptable space. Innovation as far as adaptability is concerned lay primarily in the acceptance of the trend towards more single person households evident across Europe, the need for diverse spaces of greater or lesser size for business purposes, and to accommodate the increasing trend of working from home. These forms of adaptability need to be robust and withstand the test of time.

Therefore adaptability emerged as a parameter to be included in the matrix of criteria that define the 'urban house in paradise' during Drawn Study Two, through considering the potential flexibility of an urban building. The 'House in House' concept of the dwellings explored the way in which different patterns of use can be accommodated within the dwellings proposed, in ways that leave each of the urban elements spatially coherent. The 'Japanese lunch box,' provided the conceptual instigation of this exploration. There is a potential of 12 different permutations of dwellings within each of the 32 enclosures, or 'shells' created. The four 'Town Houses' can be divided into a diverse range of sizes of space; the number of households that can be accommodated permanently within the urban block can range from 16 to 64.

The ability of the urban block to respond to changing needs, and to be capable of adapting between large and small dwelling sizes to accommodate different sizes of households, demonstrates the project's ambition to reflect the changing demographic patterns in the population. 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. Of the 3.8 million new dwellings required in England by 2021, 2.7 million, or 70 percent, are single-person households; by that time 35 percent of all households will be one person living alone.[1]

Construction Technology

Innovation at a construction level primarily lies in the way in which the project is conceived of as a two-step process. The construction of the 'supports' and the 'shells' is independent; both utilise prefabrication to minimise the period on site. This independence reflects the ability of the block to adapt to subsequent changes, through the re-arrangement of the 'shells' within the unchanged 'supports'. This focus on longevity reflects one of the Study's responses to the demand for increasing the sustainability of construction.

In order to dovetail the provision of services with the adaptability of space built into the project, all service ducts are designed to be integral with the primary vertical structural elements. The standardised bays of concrete core risers that form the spatial bays would be clad in prefabricated panels. Internal standardisation was created through prefabricated kitchen and bathroom units.

Innovation at a construction level primarily lies in the way in which the project can be cost-effectively and efficiently built, and is conceived of as a two-step process. The chosen technological strategy provides structural and services 'support' which can be inhabited and which can accept change. The erection of the fundamental, but unseen, concrete skeleton to the building is kept as short as possible through the use of pre cast concrete, standardised structural elements. The initial consideration of the duration of the construction of the 'urban house in paradise', through the site as a place of assembly, was therefore initially considered in the design of Drawn Studies One and Two, but was increasingly informed by other sources.

The second step, the site as a place of assembly, refers to the positioning and the fixing of secondary, factory-made, elements, manageable by a man in a team or by tower crane, and which complete the shells as a weather-tight envelope for the varying forms of urban inhabitation proposed. All internal partitions and service installations are considered as sub-assemblies that can be joined to the primary structure and which can be adapted either by

[1] Department of the Environment, Transport and the Regions. *Our Towns and Cities: The Future –*

an owner or at the point in time at which ownership changes. An internal panel system can be reconfigured at any time within the confines of the dwelling, thereby embodying Habraken's concept of the adaptability of the dwelling being possible at any moment, without any consequence on the surrounding inhabitants.

Innovation at the constructional scale needs to leave an architecture that has used its chosen technologies to achieve high visual quality. Effort was therefore invested in integrating strategic and tactical approaches to technology to be good servants of urbanity and adaptability. The integration of strategic standardised elements with the variety and richness of brickwork and ceramic surfacing establishes a philosophy for detailing. All of the street frontage buildings are built as pre cast concrete units that are pre-clad in brick and with integral insulation, with 6 standardised units per bay. Non-glazed parts of the housing elements would be clad in 'Eternit' panels with integral insulation. All glazed screens would be prefabricated steel-framed units.

The potential for adaptation to changing patterns of use and occupancy is one way in which the project is innovatory in its sustainability, through the emphasis placed upon the longevity of the structure to maximise the use of natural resources, both material and energy, that are embodied within it. Schematic decisions have been made on the servicing of the dwellings that will contribute further to the overall sustainability of the project. Two 30 kW condensing gas boilers would be provided for each three floor grouping of commercial spaces and each four floor grouping of residential spaces. These would supply 40 degree Celsius under-floor heating to each four floor grouping of residential spaces, which would be zoned to reflect the permutations or arrangements that are possible. This reflects the desired potential adaptability of the building, through removing the requirement for permanent wall space for radiators. Mechanical ventilation with heat recovery units and with humidity control would ensure sufficient ventilation rates within an airtight structure.

The performance of Drawn Study Two in terms of the criteria of the 'urban house in paradise' can be seen in the table overleaf. As this Drawn Study was also intended as an initial exploratory exercise, not all of the benchmarks have been evaluated. It was not considered relevant to evaluate the performance of a project against criteria that were not accounted for during the design process.

Delivering an Urban Renaissance, London: HMSO, November 2000.

Criteria		Benchmarks
		Glasgow: Scale of the Dwelling
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		Not Assessed
CO2 emissions: On Site Construction Processes: kgCO2.m-2		Not Assessed
Carbon intensity: kg.kWh-1		0.24
Construction period: weeks per dwelling		Not Assessed
Contextual significance of site: Qualitative		Assessed in Drawn Study 1
Deconstruction and demolition: Recycling materials: Percent		Not Assessed
Design life span: Years		>60
Density:	quantitative: p.ha-1	Assessed in Drawn Study 1
	qualitative	Assessed in Drawn Study 1
Diveristy: programmes.ha-1		Assessed in Drawn Study 1
Domestic waste:	refuse: kg.p-1.wk-1	Not Assessed
	recycled: kg.p-1.wk-1	Not Assessed
Ecological significance of the site: Percent and qualitative		Assessed in Drawn Study 1
Ecological weight: embodied energy: kWh.m-2		Not Assessed
Ecological weight: CO2 emissions: kgCO2.m-2		Not Assessed
Energy consumption: construction: kWh.m-2		Not Assessed
Energy consumption: inhabitation: kWh.m-2.a-1		Not Assessed
Energy generation: kWh.m-2.a-1		0
Green space: Percent		Assessed in Drawn Study 1
Lifecycle cost:	Construction: £.m-2.a-1	Not Assessed
	Energy: £.m-2.a-1	Not Assessed
	Water: £.p-1.a-1	Not Assessed
Nitrogen oxide emissions: mg.kWh-1		70
Other ecological impacts of materials: Qualitative, g.kWh-1		Not Assessed
Other greenhouse gas emissions: g.kg-1		Not Assessed
Pollution: energy consumption inhabitation: g.kWh-1		Not Assessed
Procurement strategy: Qualitative		Not Assessed
Quality of internal environment:	indoor pollution: Qualitative	Not Assessed
	daylight: living, kitchen, beds: Percent	2.4, 1.5, 1.6
	ventilation: ac.h-1	0.5
	airtightness: ac.h-1 at 50 Pa	Not Assessed
Recycling construction waste: Percent		Not Assessed
Adaptability: Internal loadbearing walls: Internal walls		0
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	27.0
	3 persons: m2.p-1	24.0
	4 persons: m2.p-1	31.2
	5 persons: m2.p-1	Not Applicable
	6 persons: m2.p-1	Not Applicable
	7 persons: m2.p-1	Not Applicable
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	86.4
	3 persons: m3.p-1	76.8
	4 persons: m3.p-1	99.6
	5 persons: m3.p-1	Not Applicable
	6 persons: m3.p-1	Not Applicable
	7 persons: m3.p-1	Not Applicable
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance:	Roof: W.m-2.K-1	Not Assessed
	Exposed walls: W.m-2.K-1	Not Assessed
	Ground and exposed floors: W.m-2.K-1	Not Assessed
	Windows and rooflights: W.m-2.K-1	Not Assessed
	Opaque outer doors: W.m-2.K-1	Not Assessed
Use of recycled materials: Percent		Not Assessed
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Not Assessed
Water consumption: inhabitation:	potable: l.p-1.d-1	160
	rain and grey: l.p-1.d-1	0
	total: l.p-1.d-1	160

Benchmark performance of Drawn Study 2

Drawn Study Two

Residential spaces within the urban block are accommodated within the four storey 'Town Houses'. These are supported over the 'Merchant Houses' by the five pairs of ribs, or 'supports', that structure the block. At ground level the ribs are pierced by the axis, or lane, and contain the vertical circulation leading to the dwellings.

The Merchant House and the Town House were identified as two traditional forms of housing in Glasgow which historically have provided long-lasting adaptable space and that bear re-interpretation. The conceptual 'Town House' contains residential accommodation, which is located over the 'Merchant Houses'. Access to the dwellings is achieved via the semi-private axis cutting through the site between the two courtyards. Each of the five pairs of ribs, or 'supports', that structure the urban block has vertical circulation leading to the dwellings.

The dwellings themselves are located on the four highest levels at the centre of the site. The cross-sectional profile is based upon the need to bring natural light into the section, and provide different dwelling sizes. The ribs that act as circulation cores to the housing are conceived of as buildings in themselves, and can accommodate rooms for students, guests and others among more itinerant groups of urban dwellers. These dwellings for transient inhabitants can be both single and double storey spaces. Each rib could provide access for between 8 and 20 dwellings.

House in House - Adaptability

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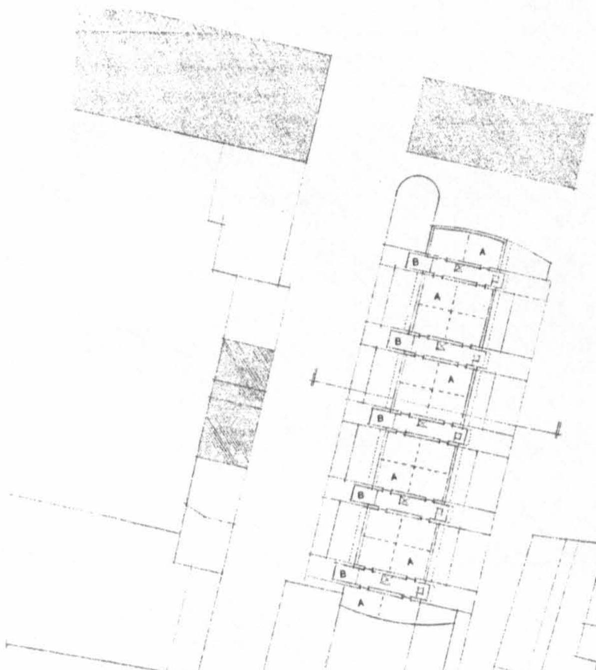
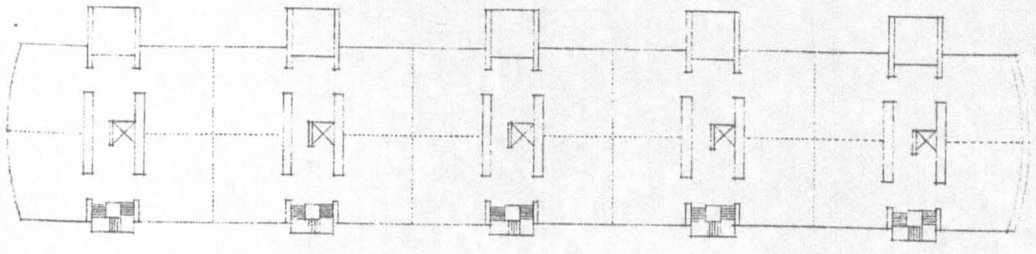
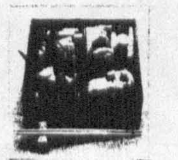
The ability of the urban block to respond to changing needs, and to be capable of adapting between large and small dwelling sizes to accommodate different sizes of households, demonstrates the project's ambition to reflect the changing demographic patterns in the population. Only two thirds of the increase 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 has fallen from 2.9 to 2.7 inhabitants. Of the 3.8 million new dwellings required in England by 2021, 2.7 million, or 70 percent, are single-person households; by that time 35 percent of all households will be one person living alone.



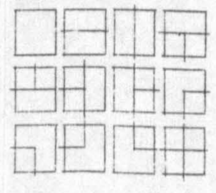


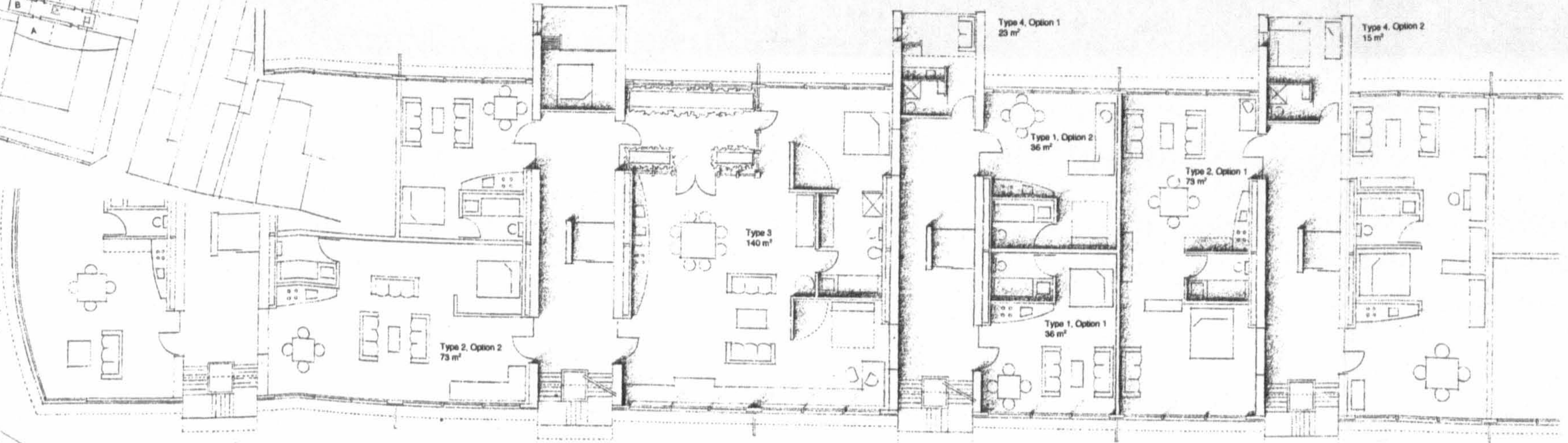
Free plan and ribs, 1:200
'Supports' and 'Shells'

The Japanese lunchbox
As a concept of objects within adaptable space

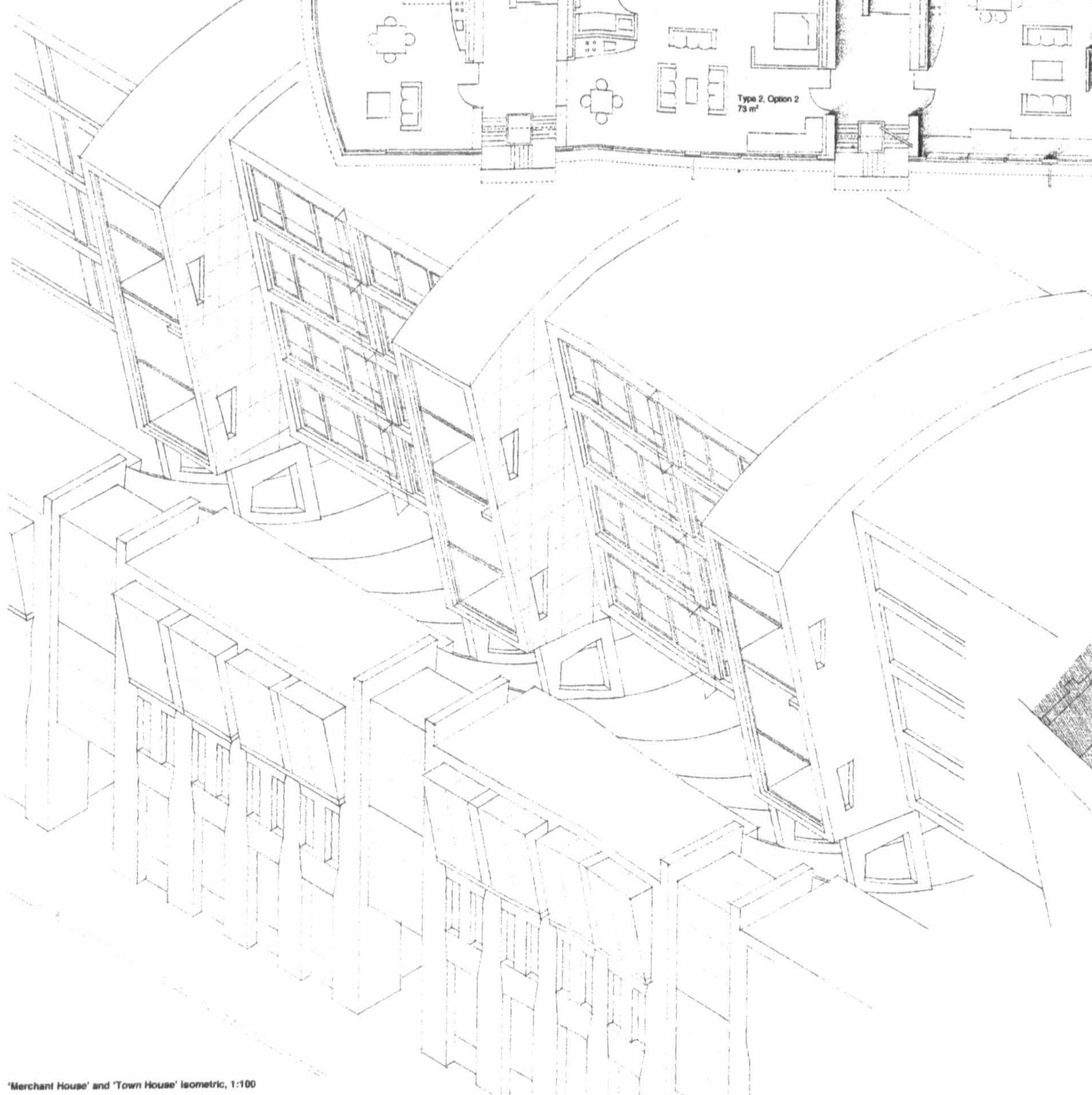


Permutations of adaptability of 'Town House'
64 interchangeable variations

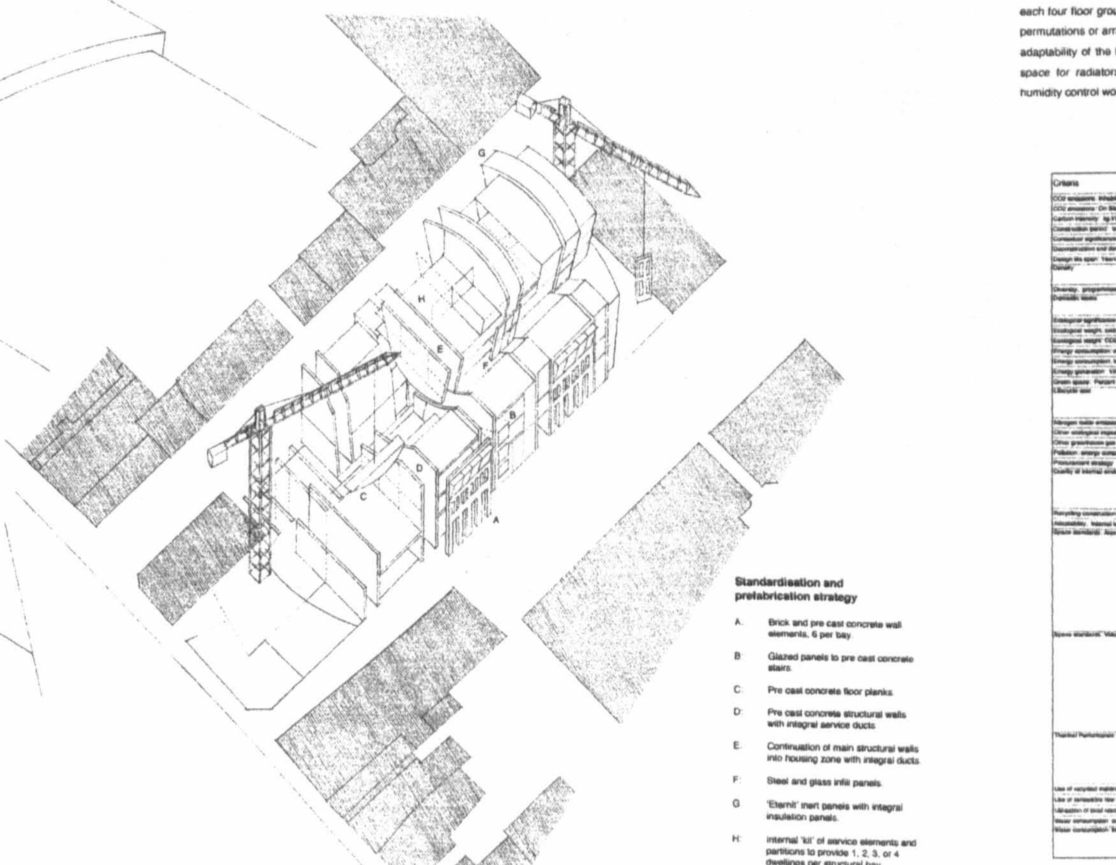




Dwelling arrangements, 1:100



'Merchant House' and 'Town House' isometric, 1:100



Construction axonometric, 1:500

Standardisation and prefabrication strategy

A. Brick and pre cast concrete wall elements, 6 per bay.

B: Glazed panels to pre cast concrete stairs.

C: Pre cast concrete floor planks.

D: Pre cast concrete structural walls with integral service ducts.

E. Continuation of main structural walls into housing zone with integral ducts.

F: Steel and glass infill panels.

G: 'Eternit' inert panels with integral insulation panels.

H: Internal 'kit' of service elements and partitions to provide 1, 2, 3, or 4 dwellings per structural bay.

Glasgow: Scale of the Dwelling

Construction Technology

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In order to dovetail the provision of services with the adaptability of space built into the project, all service ducts are designed to be integrated into the primary vertical structural elements. The standardised bays of concrete core risers that form the spatial bays would be clad in prefabricated panels. Internal standardisation was created through prefabricated kitchen and bathroom units.

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The second step, the site as a place of assembly, refers to the positioning and the fixing of secondary, factory-made, elements, manageable by an individual within a team or by tower crane, and which complete the shells as a weather-tight envelope for the varying forms of urban inhabitation proposed. All internal partitions and service installations are considered as sub-assemblies that can be joined to the primary structure, and which can be adapted either by an owner or at the point in time at which ownership changes. An internal panel system can be reconfigured at any time within the confines of the dwelling, thereby embodying Habraken's concept of the adaptability of the dwelling being possible at any moment, without any consequence on the surrounding inhabitants.

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Criteria		Benchmarks: Glasgow: Scale of the Dwelling
CO2 emissions: Inhabitation: kgCO2 m-2 a-1		Not Assessed
CO2 emissions: On Site Construction Processes: kgCO2 m-2		Not Assessed
Carbon intensity: kg kWh-1		[illegible]
Construction period: weeks per dwelling		Not Assessed
Contextual significance of site: Qualitative		Assessed in Drawn Study 1
Deconstruction and demolition: Recycling materials: Percent		Not Assessed
Design life span: Years		[illegible]
Density	quantitative: p.ha-1	Assessed in Drawn Study 1
	qualitative	Assessed in Drawn Study 1
Diversity: programmes.ha-1		Assessed in Drawn Study 1
Domestic waste	refuse: kg p-1 wk-1	Not Assessed
	recycled: kg p-1 wk-1	Not Assessed
Ecological significance of the site: Percent and qualitative		Assessed in Drawn Study 1
Ecological weight: embodied energy: kWh m-2		Not Assessed
Ecological weight: CO2 emissions: kgCO2 m-2		Not Assessed
Energy consumption: construction: kWh m-2		Not Assessed
Energy consumption: inhabitation: kWh m-2 a-1		Not Assessed
Energy generation: kWh m-2 a-1		0
Green space: Percent		Assessed in Drawn Study 1
Lifecycle cost	Construction: £ m-2 a-1	Not Assessed
	Energy: £ m-2 a-1	Not Assessed
	Water: £ p-1 a-1	Not Assessed
Nitrogen oxide emissions: mg kWh-1		[illegible]
Other ecological impacts of materials: Qualitative, g kWh-1		Not Assessed
Other greenhouse gas emissions: g kg-1		Not Assessed
Pollution: energy consumption inhabitation: g kWh-1		Not Assessed
Procurement strategy: Qualitative		Not Assessed
Quality of internal environment	indoor pollution: Qualitative	Not Assessed
	daylight: living, kitchen, beds: Percent	[illegible]
	ventilation: ac h-1	[illegible]
	airtightness: ac h-1 at 50 Pa	Not Assessed
Recycling construction waste: Percent		Not Assessed
Adaptability: Internal loadbearing walls: Internal walls		0
Space standards: Area	1 person: m2 p-1	Not Applicable
	2 persons: m2 p-1	[illegible]
	3 persons: m2 p-1	[illegible]
	4 persons: m2 p-1	[illegible]
	5 persons: m2 p-1	Not Applicable
	6 persons: m2 p-1	Not Applicable
	7 persons: m2 p-1	Not Applicable
	8 persons: m2 p-1	Not Applicable
	9 persons: m2 p-1	Not Applicable
	10 persons: m2 p-1	Not Applicable
Space standards: Volume	1 person: m3 p-1	Not Applicable
	2 persons: m3 p-1	[illegible]
	3 persons: m3 p-1	[illegible]
	4 persons: m3 p-1	[illegible]
	5 persons: m3 p-1	Not Applicable
	6 persons: m3 p-1	Not Applicable
	7 persons: m3 p-1	Not Applicable
	8 persons: m3 p-1	Not Applicable
	9 persons: m3 p-1	Not Applicable
	10 persons: m3 p-1	Not Applicable
Thermal Performance	Roof: W m-2 K-1	Not Assessed
	Exposed walls: W m-2 K-1	Not Assessed
	Ground and exposed floors: W m-2 K-1	Not Assessed
	Windows and rooflights: W m-2 K-1	Not Assessed
	Opaque outer doors: W m-2 K-1	Not Assessed
Use of recycled materials: Percent		Not Assessed
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: [illegible]		Not Assessed
Water consumption: construction: l m-2		Not Assessed
Water consumption: inhabitation	potable: l p-1 d-1	[illegible]
	rain and grey: l p-1 d-1	0
	total: l p-1 d-1	[illegible]

Drawn Study Three

Allerton Bywater: Scale of the Urban Grain

Drawn Study Three

Allerton Bywater: Scale of the Urban Grain

Drawn Studies 3, 4 and 5 were generated through partial involvement with the development of the winning submission for the second Millennium Community Competition in Allerton Bywater, on the eastern side of Leeds. Although the Studies have been evolved as identifiably individual pieces of work, involvement as part of a wider team in developing the bid facilitated pursuing the Studies to a level of resolution that otherwise would not have been possible, such as the costing determined by quantity surveyors Davis Langdon Everest, and the response and input from the national house builders Barratt, Miller and Gleeson Homes.

The Millennium Community competitions have been initiated by the Department of the Environment, Transport and the Regions, through the quango organisation English Partnerships. They are intended to demonstrate the level of sustainable innovation that is achievable within the construction industry through mixed function projects, of which housing is a significant component, as well as the redevelopment of brownfield land, and embracing the agendas of the Movement for Innovation and Construction Best Practice Programme. The competition in Allerton Bywater was launched in July 1998; first stage submissions were made in September 1998, and the final submissions in February 1999.

Historical Antecedence and Context

Allerton Bywater has been associated with mining since the Middle Ages, although the colliery itself was not established until 1878. The competition was set for the 23 hectare site of the former colliery, which was closed in 1992 with the consequent decimation of the village's employment and sense of identity.

Allerton Bywater is a former colliery village with an existing population of around 4,000 people in 1,600 dwellings. The village has been associated with mining since the Middle Ages, although the colliery itself was not established until circa 1878. In 1894 the Leeds to Castleford railway bisected the site, a fragment of which still remains. Situated at the north edge of the site are the headquarters for the Regional Offices of British Coal, which stand empty, and were the backdrop for confrontation during the 1980's miner's strike. The majority of the remaining above ground structures were cleared and the site levelled in 1995, following the closure of the pit in 1992, with the consequent decimation of the village's employment and sense of identity. The linear form of the village is bounded to the north by the former Leeds to Castleford railway, which is now a part of the strategic cycleway network that is to be linked into the Trans-Pennine cycle network, and to the south by the floodplain of the River Aire; it is terminated at the eastern end by the colliery site itself.

The competition was set by English Partnerships for the 23.1 hectare site of the former colliery. The brief offered a reclaimed, remediated, brownfield site for sustainable, mixed-use development, which would both integrate and help regenerate the existing community. It was intended that the submission would constitute a blueprint for the regeneration of other colliery communities.

The colliery site itself is bounded to the north by Park Lane, beyond which is Kippax Park, an open area of countryside giving views to the low-lying hills beyond. The main road to Castleford forms a boundary at the eastern edge of the site, which lies on the line of a Roman road. To the south is Station Road. The historic core of the village, including the church and churchyard and vacant former Primary School creates the western boundary. Where Station Road joins Park Lane, beyond the western boundary of the site, is the new primary school, and this junction forms a very weak psychological centre to the village.

The River Aire, which provides rich environmental and ecological habitats including extensive wetlands, passes just south of the site. Still navigable at this point, it used to provide transportation for the coal mined in the colliery site.

Conceptual Basis of the Grain Structure

Two cross streets that bisect the site form the principal organisational layer of the masterplan, dividing the site into unequal quadrants within which an intricate structure of dwellings, gardens, allotments and open space is woven. The Drawn Study focussed upon the two western quadrants. The grain is interpreted from the structure of the traditional Yorkshire village.

The hieroglyph of urban design, Cardo Decumanus, forms the principal organisational layer of the whole masterplan; two cross streets bisect the site, one running between east and west, and the other between north and south, at the centre of which is a new village square. The 'Decumanus' axis is termed the 'ecological street', and is predominantly a pedestrian route. Terminating this at the western end the competition submission also proposed a new village green that would act as a new geographical and psychological focal point for Allerton Bywater as a whole; a fulcrum about which the old and new would be linked. The cross axes create four quadrants to the overall masterplan; within each quadrant an intricate structure of dwellings, gardens, and allotments is woven about a network of, primarily pedestrian, routes. The first phase was originally envisaged for the western side of the north to south route, adjoining the existing village. Therefore it was on this part of the site that the Drawn Study of the urban grain was focussed.

The 'grain' is the structure of the built form within each of the four quadrants of the plan, conceived of as a network of buildings and spaces; it is intended to be more complex than that of typical new-build housing developments.[1] Both in terms of form and materiality the grain has layers that articulate movement from the relative formality of the street front, which is faced in traditional Yorkshire sandstone, inwards via lanes, toward the more informal interior of the quadrant, where materials such as render and timber are prevalent. At the centre of the southwestern quadrant is a small park, overlooked and therefore a safe play space for young children, and allotment gardens for the more sustainable production of food. The grain is intended to have a robust nature, reflected also in the architecture and technology of the dwelling, that enables it to evolve over time whilst retaining its essence and reflection of the conceptual underpinning.

The grain has short runs of wide frontage dwellings in terraces, and attempts to achieve a higher density using a contemporary reinterpretation of the structure of successful Yorkshire villages, such as Ripley, Grassington and Settle. Thereby the grain attempts to respond to the wider historical antecedence of the vernacular of Yorkshire villages, in addition to the immediate influences surrounding the site that epitomise the legacy of the industrial landscape of the 19^{th} century. The terraces of dwellings also help to reduce energy consumption, as fewer walls are externally facing; the wide frontage dwelling maximises daylight into interior space and solar gain, where appropriate.

Contemporary design precedents for the grain of the site at Allerton Bywater include projects such as Dianas Have in Copenhagen, by Tegnestuen Vandkunsten, and Borneo

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[1] Aire Regeneration Partnership. *contributing to a renaissance - volumes 1 and 2*, unpublished submission for the Allerton Bywater Millennium Community competition, February 1999.

Sporenburg in Amsterdam, by West 8. Common to both of these, and relevant to the creation of what is essentially an urban village at Allerton Bywater, is the intention to integrate urban elements and density with rural attributes, creating counterpoint between density and open space.

There is a hierarchy of three principal types of open space envisaged within the area of the Drawn Study: the private garden, the semi-public allotments and pocket parks, and the primary public open spaces. The private garden is exclusive to the realm of the dwelling. Within each of the four quadrants of the masterplan there are semi-public allotments and pocket parks, provided for the dwellings in the immediate vicinity. These form the central space to the grain of each quadrant, at least psychologically if not geographically, and are intended to generate incidental interaction between the inhabitants, reversing the introspection common in new housing developments. Public open spaces, both hard and soft, are created at significant points within the overall structure of the masterplan, such as the gardens to the east of the Drawn Study and at the principal square, located at the intersection between the 'Cardo' and the 'Decumanus'

The fabric of the grain has both north to south and east to west orientations. Whilst the former might be considered more desirable in maximising passive solar gain, a balance was required to create diversity in the fabric of the masterplan, and to create a micro-climate that responds to the exposure of the site from the northerly and prevailing westerly winds.

Permeability

The layering of the quadrants, from the formality of the street via lanes into the relative informality of the core, influences the permeability of the grain. Pedestrians and cyclist predominate, to whom the car is subservient.

The structure of the grain intended to promote walking and cycling as opposed to the use of the car. Precedents such as the Dutch Woonerf, which is designed as a multi-functional street into which cars enter under sufferance,[2] suggest that this is more successful where primary activities are integrated into an uninterrupted network of routes. As described above, the grain has layers as it moves from the external edges of each quadrant, bounded

[2] Hough, Michael. *Cities and Natural Process*, London: Routledge, 1995.

by the site edges and cross axes, toward to more informal interior of the block. This layering is also manifest in the permeability of the grain.

The car is perceived as subservient to pedestrians and cyclists throughout the site, with calming achieved primarily through the articulation of the grain; the principal east to west link is essentially car free. Changes in materiality are introduced at thresholds, indicating that a vehicle has entered a predominantly pedestrian and cycle territory; moving toward the interior of the block the speed of vehicles is reduced further. 0.75 covered car parking spaces per dwelling are provided in small clusters within covered spaces, with additional parking for visitors.

Density

Counterpoint to the higher density of dwellings is provided by the provision of open space and the open countryside to the north of the site. Although almost twice the density of the typical speculative greenfield housing development, it is below the value proposed by Friends of the Earth as a sustainable urban density.

The density of housing is intended to be higher than that which might be associated with the site's semi-rural location; more 'urban' than 'village'. This density is mediated through providing counterpoint, both as open space with the masterplan and the open countryside beyond.

In total the area of the site of the Drawn Study was 6.14 hectares. Excluding the strategic open spaces, the area considered was 4.70 hectares. Within this area 218 dwellings have been incorporated, with a total designed occupancy of 953 people. Therefore the net residential density that was achieved in the grain at Allerton Bywater has been calculated as 203 people per hectare. Although this is more than double that of the typical greenfield housing development, it is below the lower threshold, of 225 people per hectare, proposed by Friends of the Earth as a sustainable urban density, and is significantly below the benchmark proposed for the 'urban house in paradise' of 375 people per hectare. Most notably this is a consequence of the low vertical scale of the design.

Diversity

Although a specific intention was to create a mixed-use project, the low scale of development and more remote location has meant that the Study was not able to achieve a programmatic diversity as high as that which might be expected in a more centralised, urban location. The mix of dwellings is spatial in character as well as numerical, through the articulation of low-rise single dwellings and higher elements containing flats to create spatial definition and focus at strategic locations within the urban grain.

A specific intention has been to create a mixed function project, rather than a mono-functional housing estate, increasing the diversity of the grain in a functional as well as architectural manner. This also has the advantage of benefiting socio-economic sustainability, through local employment generation and spending, and additional ecological sustainability, through reduced transportation. Within the scope of Drawn Study 3 these mixed-uses include the following. At significant corners of the quadrants, along the primary routes, three storey buildings accommodate flats over retail units. The refurbished and expanded former primary school, which lies just outside of the site boundary, would provide a location for the library, which has moved from the new primary school to create more space required due to the influx of families to the new housing. It is also proposed that the recently formed parish council and the Village Company, charged with the responsibility of managing the long-term interest of the new community, would be based within this building. Other functions proposed include a doctor's surgery and post office. It was a specific intention of the brief that it was a development, and not a design, competition; this distinction emphasised the importance placed upon viability and deliverability. Due to the much lower scale of development and more remote location, the Drawn Study was not able to achieve diversity as high as that which might be expected in a more centralised, urban location. A total of 8 different programmes have been incorporated into the 6.18 hectares of the Drawn Study; this can be equated to a benchmark of programmatic diversity of 1.3 programmes per hectare.

The mix of dwellings is based upon market analysis at the time of the competition submission. Therefore 25 percent of the dwellings are notional two-bedroom, 40 percent notional three-bedroom and 35 percent notional four-bedroom. The use of the term 'notional' in connection with the description of the dwelling types is in response to their adaptable nature, and is expanded upon in Drawn Study 4. The balance of low-rise single dwellings and the higher elements containing flats is articulated to create spatial definition and focus at strategic locations within the urban grain; therefore the mix of dwellings is spatial in character as well as numerical.

The performance of the Drawn Study in terms of the criteria of the 'urban house in paradise' can be seen in the table overleaf.

Criteria		Benchmarks
		Allerton Bywater: Urban Grain
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		Assessed in Drawn Study 5
CO2 emissions: On Site Construction Processes: kgCO2.m-2		Assessed in Drawn Study 5
Carbon intensity: kg.kWh-1		Assessed in Drawn Study 5
Construction period: weeks per dwelling		Assessed in Drawn Study 4
Contextual significance of site: Qualitative		Yes
Deconstruction and demolition: Recycling materials: Percent		Assessed in Drawn Study 5
Design life span: Years		Assessed in Drawn Study 4
Density:	quantitative: p.ha-1	203
	qualitative	Yes and Yes
Diveristy: programmes.ha-1		1.3
Domestic waste:	refuse: kg.p-1.wk-1	Assessed in Drawn Study 4
	recycled: kg.p-1.wk-1	Assessed in Drawn Study 4
Ecological significance of the site: Percent and qualitative		100, Yes and No
Ecological weight: embodied energy: kWh.m-2		Assessed in Drawn Study 5
Ecological weight: CO2 emissions: kgCO2.m-2		Assessed in Drawn Study 5
Energy consumption: construction: kWh.m-2		Assessed in Drawn Study 5
Energy consumption: inhabitation: kWh.m-2.a-1		Assessed in Drawn Study 5
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study 5
Green space: Percent		237
Lifecycle cost:	Construction: £.m-2.a-1	Assessed in Drawn Study 4
	Energy: £.m-2.a-1	Assessed in Drawn Study 4
	Water: £.p-1.a-1	Assessed in Drawn Study 4
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study 5
Other ecological impacts of materials: Qualitative, g.kWh-1		Assessed in Drawn Study 5
Other greenhouse gas emissions: g.kg-1		Assessed in Drawn Study 5
Pollution: energy consumption inhabitation: g.kWh-1		Assessed in Drawn Study 5
Procurement strategy: Qualitative		Competition
Quality of internal environment:	indoor pollution: Qualitative	Assessed in Drawn Study 5
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 5
	ventilation: ac.h-1	Assessed in Drawn Study 5
	airtightness: ac.h-1 at 50 Pa	Assessed in Drawn Study 5
Recycling construction waste: Percent		Assessed in Drawn Study 5
Adaptability: Internal loadbearing walls: Internal walls		Assessed in Drawn Study 4
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	Not Applicable
	3 persons: m2.p-1	Not Applicable
	4 persons: m2.p-1	Assessed in Drawn Study 4
	5 persons: m2.p-1	Assessed in Drawn Study 4
	6 persons: m2.p-1	Not Applicable
	7 persons: m2.p-1	Assessed in Drawn Study 4
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
	4 persons: m3.p-1	Assessed in Drawn Study 4
	5 persons: m3.p-1	Assessed in Drawn Study 4
	6 persons: m3.p-1	Not Applicable
	7 persons: m3.p-1	Assessed in Drawn Study 4
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance:	Roof: W.m-2.K-1	Assessed in Drawn Study 4
	Exposed walls: W.m-2.K-1	Assessed in Drawn Study 4
	Ground and exposed floors: W.m-2.K-1	Assessed in Drawn Study 4
	Windows and rooflights: W.m-2.K-1	Assessed in Drawn Study 4
	Opaque outer doors: W.m-2.K-1	Assessed in Drawn Study 4
Use of recycled materials: Percent		Assessed in Drawn Study 5
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Assessed in Drawn Study 5
Water consumption: inhabitation:	potable: l.p-1.d-1	Assessed in Drawn Study 4
	rain and grey: l.p-1.d-1	Assessed in Drawn Study 4
	total: l.p-1.d-1	Assessed in Drawn Study 4

Benchmark performance of Drawn Study 3

Drawn Study Three

Historical Antecedence and Context

Allerton Bywater has been associated with mining since the Middle Ages, although the colliery itself was not established until 1878. The Millennium Community competition was set for the 23 Ha site of the former colliery, which was closed in 1992.

Allerton Bywater is a former colliery village with an existing population of around 4,000 people in 1,600 dwellings. The village has been associated with mining since the Middle Ages, although the colliery itself was not established until 1878. Situated at the north edge of the site are the headquarters for the Regional Offices of British Coal, which stand empty. The majority of the remaining above ground structures were cleared and the site levelled following the closure of the pit in 1992, with the consequent decimation of the village's employment and sense of identity. The linear form of the village is bounded to the north by the former Leeds to Castleford railway and to the south by the floodplain of the River Aire; it is terminated at the eastern end by the colliery site. The site is bounded to the north by Park Lane, beyond which is an open area of countryside. The main road to Castleford forms a boundary at the eastern edge of the site, which lies on the line of a Roman road. The historic core of the village, including the church and churchyard and vacant former Primary School, creates the western boundary.

Context and full extent of the overall Masterplan of the colliery site, 1:5,000

Conceptual Basis of the Grain

Two cross streets form the principal organisational layer of the masterplan, dividing the site into unequal quadrants within which an intricate structure of dwellings, gardens, allotments and open space is woven.

The hieroglyph of urban design, Cardo Decumanus, forms the principal organisational layer of the masterplan, two cross streets bisect the site, one running between east and west and the other between north and south, at the centre of which is a new village square. The cross axes create four quadrants, within each an intricate structure of dwellings, gardens, and allotments is woven about a network of routes. The Drawn Study of the urban grain was focussed upon the western side of the north to south route.

The 'grain' is the structure of the built form within each of the quadrants. Both in terms of form and materiality the grain has layers that articulate movement from the relative formality of the street front, inwards via lanes, toward the more informal interior of the quadrant. At the centre of the southwestern quadrant are allotment gardens and a small park. The grain is intended to have a robust nature, reflected in the architecture and technology of the dwelling, that enables it to evolve over time whilst retaining its essence and reflection of the conceptual underpinning. The short runs of wide frontage dwellings in terraces attempts to achieve a higher density using a contemporary reinterpretation of the structure of successful Yorkshire villages such as Ripley. This attempts to respond to the wider historical antecedence of the vernacular of Yorkshire villages, in addition to the immediate influences surrounding the site that epitomise the legacy of the industrial landscape of the 19th century. This layering is also manifest in the permeability of the grain. The car is perceived as subservient to pedestrians and cyclists throughout the site; changes in materiality are introduced at thresholds, indicating that a vehicle has entered a predominantly pedestrian and cycle territory.

There is a hierarchy of three principal types of open space envisaged within the area of the Drawn Study: the private garden, the semi-public allotments and pocket parks, and the primary public open spaces. There are the semi-public allotments and pocket parks within each of the four quadrants of the masterplan. These form the central space to the grain of each quadrant, at least psychologically, and are intended to generate incidental interaction between the inhabitants, reversing the introspection common in new housing developments. Public open spaces are created at significant points within the overall structure of the masterplan. The fabric of the grain has both north to south and east to west orientations to create diversity in the fabric of the masterplan and microclimate

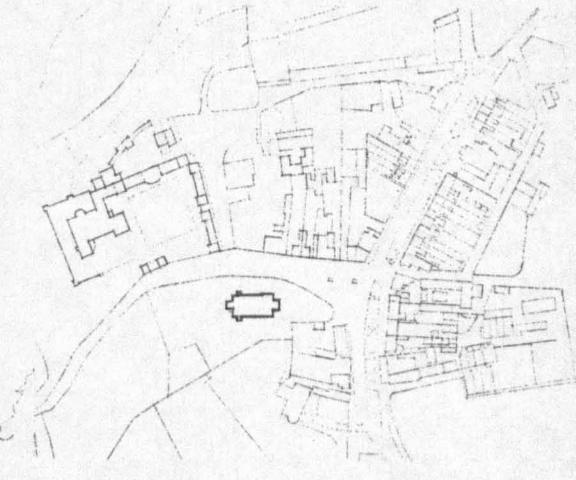
Cross section through the Grain, 1:200

Structure of the Urban Grain, 1:500

Plan Key

A South facing notional '2 bedroom' dwelling
B South facing notional '3 bedroom' dwelling
C South facing notional '4 bedroom' dwelling
D North facing notional '2 bedroom' dwelling
E North facing notional '3 bedroom' dwelling
F North facing notional '4 bedroom' dwelling
G East facing notional '2 bedroom' dwelling
H East facing notional '3 bedroom' dwelling
I East facing notional '4 bedroom' dwelling
J West facing notional '2 bedroom' dwelling
K West facing notional '3 bedroom' dwelling
L West facing notional '4 bedroom' dwelling
M Library within refurbished primary school
N Parish council and Village Company offices within extension
O Doctor's surgery
P Pharmacy and Post Office
Q Glass houses
R Water gardens
S Flats over retail space
T Allotments
U Pocket park

Allerton Bywater: Scale of the Urban Grain



Ripley – Grain of a traditional Yorkshire village, not to scale

Density

Counterpoint to the higher density of dwellings is provided by the provision of open space and the open countryside to the north of the site. Although almost twice the density of the typical speculative greenfield housing development, it is below the value proposed as a sustainable urban density.

The density of housing is higher than that which might be associated with the site's semi-rural location; more 'urban' than 'village'. The intention was to integrate urban elements and density with rural attributes, creating counterpoint between density and open space. The net residential density within the 6.14 Ha considered was 203 $p.ha^{-1}$. Although more than double that of the typical greenfield housing development it is below the lower threshold proposed by Friends of the Earth as a sustainable urban density, of 225 $p.ha^{-1}$.

Diversity

Although a mixed-use project, the low scale of development and more remote location has meant that the Study was not able to achieve a programmatic diversity as high as that of a more centralised, urban location.

At significant corners of the quadrants, along the primary routes, three storey buildings accommodate flats over retail units. The former primary school, which lies just outside of the site boundary, would provided a location for the library and offices for the Parish Council and the Village Company. Other functions proposed include a doctor's surgery and post office. Due to the much lower scale of development and more remote location, the Drawn Study was not able to achieve diversity as high as that which might be expected in a more centralised, urban location. 8 different programmes have been incorporated into the 6.18 hectares of the Drawn Study; this can be equated to a benchmark of programmatic diversity of 1.3 programmes per hectare. The mix of dwellings is spatial in character as well as numerical, through the articulation of low-rise single dwellings and higher elements containing flats to create spatial definition and focus at strategic locations within the urban grain.

Criteria		Benchmarks
		Allerton Bywater: Urban Grain
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CO2 emissions: On Site Construction Processes kgCO2.m-2		Assessed in Drawn Study 5
Carbon intensity kg.kWh-1		Assessed in Drawn Study 5
Construction period: weeks per dwelling		Assessed in Drawn Study 4
Contextual significance of site: Qualitative		Yes
Deconstruction and demolition: Recycling materials: Percent		Assessed in Drawn Study 5
Design life span: Years		Assessed in Drawn Study 4
Density	quantitative: p.ha-1	203
	qualitative	Yes and Yes
Diversity: programmes ha-1		1.3
Domestic waste	residual kg.p-1.wk-1	Assessed in Drawn Study 4
	recycled kg.p-1.wk-1	Assessed in Drawn Study 4
Ecological significance of the site: Percent and qualitative		100, Yes and No
Ecological weight: embodied energy: kWh.m-2		Assessed in Drawn Study 5
Ecological weight: CO2 emissions: kgCO2.m-2		Assessed in Drawn Study 5
Energy consumption: construction: kWh.m-2		Assessed in Drawn Study 5
Energy consumption: inhabitation: kWh.m-2.a-1		Assessed in Drawn Study 5
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study 5
Green space: Percent		[illegible]
Lifecycle cost	Construction: £.m-2.a-1	Assessed in Drawn Study 4
	Energy: £.m-2.a-1	Assessed in Drawn Study 4
	Water: £.p-1.a-1	Assessed in Drawn Study 4
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study 5
Other ecological impacts of materials: Qualitative, g.kWh-1		Assessed in Drawn Study 5
Other greenhouse gas emissions: g.kg-1		Assessed in Drawn Study 5
Pollution: energy consumption inhabitation: g.kWh-1		Assessed in Drawn Study 5
Procurement strategy: Qualitative		Competition
Quality of internal environment	indoor pollution: Qualitative	Assessed in Drawn Study 5
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 5
	ventilation: ac.h-1	Assessed in Drawn Study 5
	airtightness: ac.h-1 at 50 Pa	Assessed in Drawn Study 5
Recycling construction waste: Percent		Assessed in Drawn Study 5
Adaptability: internal loadbearing walls: internal walls		Assessed in Drawn Study 4
Space standards: Area	1 person: m2.p-1	Not Applicable
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	6 persons: m2.p-1	Not Applicable
	7 persons: m2.p-1	Assessed in Drawn Study 4
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
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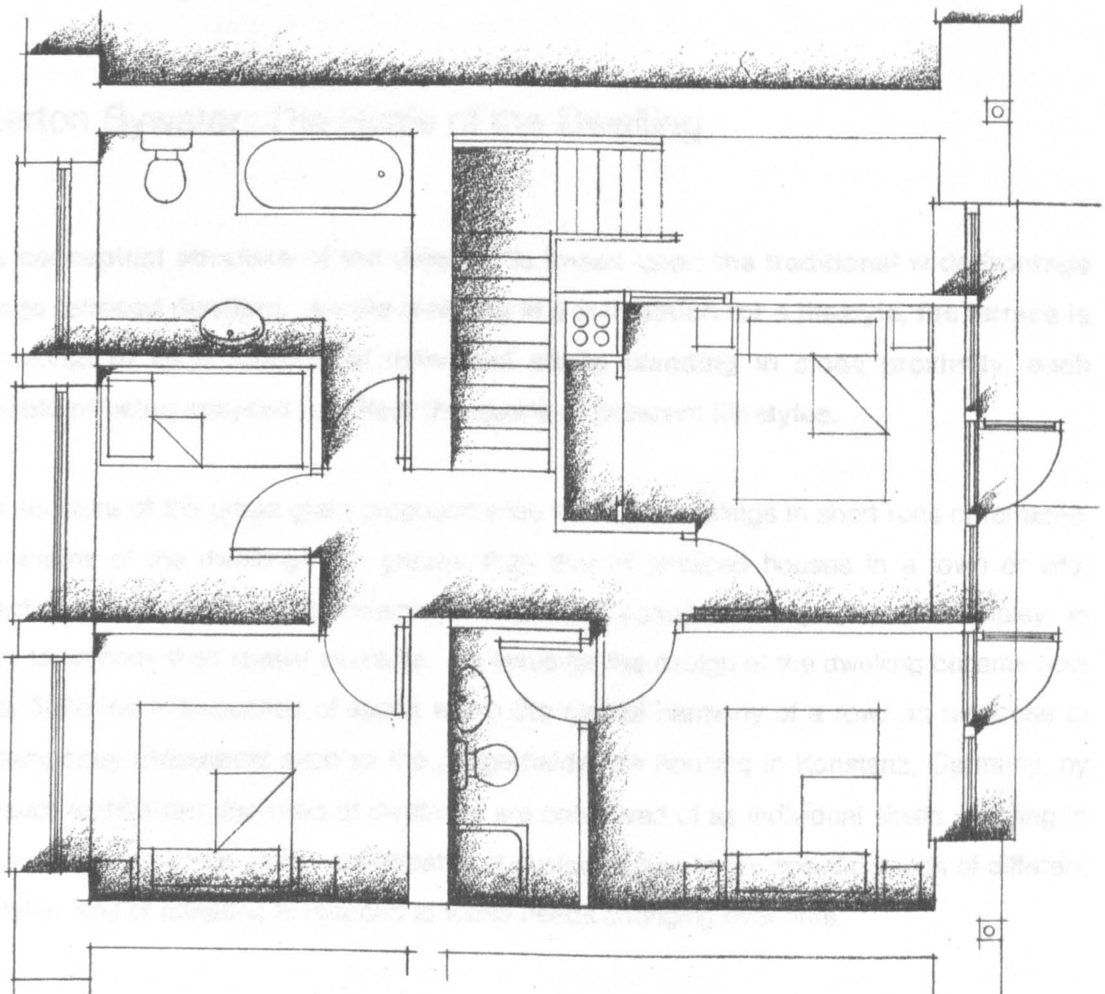
	5 persons: m3.p-1	Assessed in Drawn Study 4
	6 persons: m3.p-1	Not Applicable
	7 persons: m3.p-1	Assessed in Drawn Study 4
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance	Roof: W.m-2.K-1	Assessed in Drawn Study 4
	Exposed walls: W.m-2.K-1	Assessed in Drawn Study 4
	Ground and exposed floors: W.m-2.K-1	Assessed in Drawn Study 4
	Windows and rooflights: W.m-2.K-1	Assessed in Drawn Study 4
	Opaque outer doors: W.m-2.K-1	Assessed in Drawn Study 4
Use of recycled materials: Percent		Assessed in Drawn Study 5
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Assessed in Drawn Study 5
Water consumption: inhabitation	potable: l.p-1.d-1	Assessed in Drawn Study 4
	rain and grey: l.p-1.d-1	Assessed in Drawn Study 4
	total: l.p-1.d-1	Assessed in Drawn Study 4

Drawn Study Four



Allerton Bywater: Scale of the Dwelling

Drawn Study Four

Allerton Bywater: The Scale of the Dwelling

The conceptual structure of the dwelling is based upon the traditional wide frontage village terraced dwelling. As the dwelling is a foundation for a lifestyle, the terrace is conceived of as a number of individual shells standing in close proximity, each capable of being adapted to reflect the needs of different lifestyles.

The structure of the urban grain proposed wide frontage dwellings in short runs of terraces. The widths of the dwellings are greater than that of terraced houses in a town or city, reflecting the wide frontages endemic of traditional Yorkshire villages, such as Ripley, in order to embody their spatial structure. An issue for the design of the dwelling became how to facilitate the individuation of space within the overall harmony of a row. In response to contemporary precedents such as the Jungerhalde row housing in Konstanz, Germany, by Schaudt Architekten, the rows of dwellings are conceived of as individual shells standing in close proximity. These shells are capable of customisation to the specific needs of different lifestyles, and of adapting to respond to those needs changing over time.

To achieve the diversity desired within the grain, and to establish a micro-climate, the masterplan required that dwellings face four different orientations. Also, creating the two principal streets that bisect the site required dwellings that front both sides of the east to west and north to south axes. This presented challenges in maximising the utilisation of passive solar gain and sunlight penetration into the dwelling. To resolve this, a range of dwelling types were created that vary both in size and in terms of their principal orientation; the variety of permutations available contributes further to the diversity of the overall grain.

Dwellings within the terraces orientated east to west maximise passive solar gain through having a higher proportion of glazing facing south, and minimising the glazing that faces north. For the dwellings within terraces that run north to south, such direct penetration of the sun is not possible. The slight skew to the grid means that a small differentiation can be made by increasing the proportion of glazing that faces east over that which faces west. Within these proportions of glazing area, a response to the orientation of the dwelling within the grain, in terms of whether the south or east aspect of the dwelling faces a street, a lane or a private garden, is also made. The desirable penetration of sunlight into north to south dwellings was increased further by including a double-height space over the entrance hall and staircase, which allows sunlight entering through a roof light to be reflected into the ground and first floor. Therefore in total 12 dwelling types of 3 different sizes, responding to the 4 orientations of the urban grain, are proposed. In terms of size, these are based upon a notional two-bedroom dwelling, a notional three-bedroom dwelling and a notional four-bedroom dwelling.

To reduce the problem of noise transmission between dwellings, a shortcoming frequently associated with terraces, each party wall is composed of two independent leaves. Therefore is embodies the conceptual structure of the dwelling as individual units, standing in very close proximity so as to appear as a row.

Immediately within the entrance to each dwelling, beyond the draught lobby, is a large entrance hall. This is also intended as a small study space. Within the competition submission was the proposal that each dwelling be 'hard wired' to an Intranet managed by the Village Company. Beyond this, within the notional layouts proposed, circulation spaces are kept as small as possible in order to maximise the habitable space within the dwelling.

The brief demand that the minimisation of domestic waste, and the reduction of landfill waste to zero, should be considered. Therefore at the front of each dwelling, integrated into the porch, is a storage space with the capacity for two 'wheelie bins'. This responded to the projected long-term recycling policy of Leeds City Council, like that under trial by Bradford City Council, of dual collection. One bin is allocated for domestic refuse, whilst the other is allocated for all recyclable materials. The benchmark proposed within the submission was that waste would be reduced throughout the life span of the dwellings, from their construction, through their inhabitation, and in their eventual demolition, by 50 percent. Therefore on the basis of the benchmark analysis of the typical quantity of waste produced during inhabitation, refer to Annexe 3.11, 4.7 kg per person per week would be recycled and the same quantity would be disposed of as refuse. It was envisaged this would either be through dual collection by Leeds City Council, or more likely through private collection within the site.

Adaptability and Expandability

Conceptually each dwelling is conceived of as a structural shell, within which a prospective owner would be able to create an interior that suits a particular lifestyle, and which is capable of responding to changes in that lifestyle over time. A generic dwelling can therefore be particularised to the needs of an individual. The dwellings are also expandable, so that additional space can be added in a way that harmonises with the existing dwellings.

The term 'notional' to describe the size of the dwelling is intentional. Flexibility and adaptability were explicit aspirations within the competition brief,[1] and this has been responded to. The inclusion of adaptability within the criteria that define the 'urban house in paradise' emerged in part through this Drawn Study. The decision was made to minimise the number of internal load-bearing partitions; only four of the initial twelve types had internal load-bearing structure and the rest had none. Conceptually each dwelling is conceived of as a structural shell, within which a prospective owner would be able to create and interior that suits a particular lifestyle. This would both maximise choice in the initial layout, to suit the initial inhabitants' preferences, and the potential adaptability of the dwelling over time.

Therefore the interior of each dwelling is completely flexible, and capable of adapting to suit a variety of lifestyles. For example a dwelling could be used as both a living space and a workspace; half or all of the first floor could be dedicated to working from home. Equally, a notional four-bedroom dwelling could be built as new with, or adapted into, two large bedrooms, such as a master bedroom and teenager's or grandparents' apartment. Such an arrangement could be adapted over time to accommodate the expansion of a family, and then reconfigured as the family structure changes again when children move out. Therefore a generic dwelling can be particularised to the needs of an individual, and the inhabitants can choose to adapt their dwelling to suit their changing needs, rather than be forced to move.

It is also proposed that the modularised construction technology used to build the dwelling in the first instance will facilitate in expanding it at a later date. Thereby an extension will integrate and harmonise with the surrounding built form, as opposed to appearing as an ad-hoc addition. This potential for expanding the dwelling is integrated into the design of the initial dwellings. For example, the cross-section of the two-bedroom dwelling, probably the most likely to be extended, replicates the front portion of the cross-section of the four-bedroom dwelling; therefore simply adding a mono-pitch roof can convert the former type into the latter. The expansion of the dwelling could be over one storey or two, and could increase the area of existing living or sleeping areas, or provide additional sleeping areas, a workspace or a conservatory. The capacity to expand contributes further to the ability of the dwelling to respond to changing needs, as opposed to forcing the inhabitants to move.

The ability of the dwelling to respond to changing needs is one way in which the life span of the dwelling is maximised. Increasing the longevity of the dwelling maximises the efficiency of use of the materials and energy embodied within it, and therefore is a way in which the ecological sustainability of the project can be increased. A design life span of 100 years, reflected in the construction technology and materials used to construct the shell of the dwelling, is proposed.

Materiality

The different materiality of the exterior of the dwellings is another way in which the diversity of the urban grain is increased. It changes to provide increasing informality, from the sandstone of the streets, through the lanes, to the interior of the quadrants. This also provides orientation as people move through the grain.

As described in Drawn Study 3, in terms of materiality the urban grain of the masterplan has layers that articulate movement from the relative formality of the street front, inwards via lanes, toward the more informal interior of each quadrant. This variation in materiality is a way in which the diversity of the overall plan is increased, creating different identities within the different parts of the plan that can orientate people as they move through it. On the street frontages of the two cross axes the predominant material is traditional Yorkshire sandstone; as one moves to the less formal edges of the blocks, which face the edges of the site, this becomes terracotta; moving through the lanes toward the informal interiors of the quadrants, which surround the allotments and park, render and timber are prevalent. This is another way in which the individuality of the dwelling is achieved. The different materials used within the grain are created on the generic structure of the dwellings as rainscreen cladding, the detail of which is described in Drawn Study 5. The core material of

[1] English Partnerships, *Millennium Communities Competition - Allerton Bywater Stage Two*

the dwellings, from which the rainscreens are hung, is concrete; the material implications on the technology of the dwelling's construction are also discussed in Drawn Study 5.

Space Standards

The specific intention was made to increase both the area and the habitable volume of the dwelling over that of the typical product of a national house builder, to improve its desirability. Subsequently this became one of the criteria of the 'urban house in paradise'. Space use within the dwelling was also studied, as an indicator of spatial preferences in new housing. The high ceilings also benefit daylight penetration and ventilation.

Space standards, in terms of area and volume, are criteria of the 'urban house in paradise' that have emerged out of Drawn Study 4. The proposed cost savings achieved through rational, standardised, prefabricated construction would be used, in part, to create a larger dwelling. It was considered that both the area and the volume of the dwelling should be studied in terms of defining the new space standards for the study, as opposed to the traditional trend of only considering area.

Extensive analysis of the products of a national house builder and a national housing association was undertaken to establish the current standards from which to propose a benchmark increase. The space standards analysis also studied the percentage of space use, as an indicator of spatial preferences in new housing. A more detailed account of this study, with the results of this analysis, is given in Annexe 3.30 under the criterion of Space Standards: Area, refer to volume 3. The benchmark for the Drawn Study was set at an average increase of 10 percent for the area and 35 percent for the volume of the dwelling. The latter is achieved in part, in addition to the increase in area, by utilising the volume within the roof pitch to maximise the ratio of inhabited space to enclosed space, thereby maximising the efficiency of the dwelling's envelope. In addition the floor to ceiling height of the ground floor is set at 3.0 metres. The increase in area and volume over that of the typical speculative dwelling was envisaged as one way in which the desirability of the dwelling will be increased.

Development Brief, 1998.

The high ceilings were also incorporated into the design of the dwellings to benefit daylight penetration into the dwelling, and also the circulation of air. The performance of the Drawn Study in terms of the mean average daylight factors for the dwelling types proposed has been calculated, and is summarised in the following table.

Dwelling	Mean Average Daylight Factor (percent)		
	Living spaces	Kitchen	Bedroom
2 Bed equivalent	5.75	-	3.6
3 Bed equivalent	4.5	2.0	3.4
4 Bed equivalent	3.5	1.7	3.1
Total mean	**4.6**	**1.9**	**3.4**

Average Daylight Factors for Drawn Study Four

The value for the kitchen is slightly below the standard of BS 8206: Part 2, which is 1.5 percent for living spaces, 2 percent for kitchens and 1 percent for bedrooms. However, the values for the other spaces within the dwellings are significantly above that of the British Standard.

Cost

A build cost benchmark was established as 506 £.m^{2}; a 15 percent reduction on the build cost of a typical dwelling. The energy costs were also calculated, on the basis of predicted consumption, and were 58 percent, or £250.93 per annum, less that of the typical three-bedroom dwelling.

The competition submissions took on board the cost reduction philosophy of the Movement for Innovation. The intention of cutting construction costs was benchmarked by a proposed reduction of up to 19 percent in the first year, and by up to 30 percent at minimum after three years, when comparing like for like in terms of space standards and site conditions. A construction cost benchmark was proposed for the build cost of a typical dwelling of 592 £.m^{-2}. The proposed construction cost of the dwellings was predicted as 560 £.m^{-2}.[2]

[2] Aire Regeneration Partnership. *contribution to a renaissance 2 - Annexes to the Report*, February 1999.

However, this new benchmark also included a higher ratio of habitable volume to floor area and a higher standard of specification in thermal performance, and higher performance standards in energy, water and waste consumption. English Partnerships subsequently demanded the benchmark of a maximum construction cost of 506 £.m^{-2}. This constituted, therefore, the benchmark for the project; a 15 percent reduction on the build cost of a typical dwelling. This value can be converted into a lifecycle construction cost that will take into account the design life expectancy of the dwelling of 100 years. Dividing this value by 100 years gives a construction cost per annum over the dwelling's design life of 5.06 £.m^{-2}.

The annual energy costs of the dwellings in the Drawn Study were also estimated; this is based upon the predicted energy consumption, summarised in Drawn Study 5.

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

Energy consumption and costs for the Drawn Study 4 dwelling

It is worthy of note is that for one year's consumption, excluding standing charges, the energy costs of the Drawn Study are 42 percent that of the typical three bedroom dwelling, or £250.93 less, as calculated in Annexe 3.19, refer to volume 3. Clearly this would contribute significantly to the disposable income of the inhabitants, increasing the social sustainability of the project in addition to its ecological sustainability.

The performance of the Drawn Study in terms of the criteria of the 'urban house in paradise' can be seen in the table overleaf.

Criteria		Benchmarks
		Allerton Bywater: Dwelling
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		Assessed in Drawn Study 5
CO2 emissions: On Site Construction Processes: kgCO2.m-2		Assessed in Drawn Study 5
Carbon intensity: kg.kWh-1		Assessed in Drawn Study 5
Construction period: weeks per dwelling		4
Contextual significance of site: Qualitative		Assessed in Drawn Study 3
Deconstruction and demolition: Recycling materials: Percent		Assessed in Drawn Study 5
Design life span: Years		100
Density:	quantitative: p.ha-1	Assessed in Drawn Study 3
	qualitative	Assessed in Drawn Study 3
Diveristy: programmes.ha-1		Assessed in Drawn Study 3
Domestic waste:	refuse: kg.p-1.wk-1	4.8
	recycled: kg.p-1.wk-1	4.8
Ecological significance of the site: Percent and qualitative		Assessed in Drawn Study 3
Ecological weight: embodied energy: kWh.m-2		Assessed in Drawn Study 5
Ecological weight: CO2 emissions: kgCO2.m-2		Assessed in Drawn Study 5
Energy consumption: construction: kWh.m-2		Assessed in Drawn Study 5
Energy consumption: inhabitation: kWh.m-2.a-1		Assessed in Drawn Study 5
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study 5
Green space: Percent		Assessed in Drawn Study 3
Lifecycle cost:	Construction: £.m-2.a-1	5.06
	Energy: £.m-2.a-1	7.76
	Water: £.p-1.a-1	280.54
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study 5
Other ecological impacts of materials: Qualitative, g.kWh-1		Assessed in Drawn Study 5
Other greenhouse gas emissions: g.kg-1		Assessed in Drawn Study 5
Pollution: energy consumption inhabitation: g.kWh-1		Assessed in Drawn Study 5
Procurement strategy: Qualitative		Assessed in Drawn Study 3
Quality of internal environment:	indoor pollution: Qualitative	Assessed in Drawn Study 5
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 5
	ventilation: ac.h-1	Assessed in Drawn Study 5
	airtightness: ac.h-1 at 50 Pa	Assessed in Drawn Study 5
Recycling construction waste: Percent		Assessed in Drawn Study 5
Adaptability: Internal loadbearing walls: Internal walls		0
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	Not Applicable
	3 persons: m2.p-1	Not Applicable
	4 persons: m2.p-1	18.9
	5 persons: m2.p-1	19.6
	6 persons: m2.p-1	Not Applicable
	7 persons: m2.p-1	20.3
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
	4 persons: m3.p-1	55.3
	5 persons: m3.p-1	57.6
	6 persons: m3.p-1	Not Applicable
	7 persons: m3.p-1	60.9
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance:	Roof: W.m-2.K-1	0.14
	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	2.90
	Opaque outer doors: W.m-2.K-1	3.00
Use of recycled materials: Percent		Assessed in Drawn Study 5
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Assessed in Drawn Study 5
Water consumption: inhabitation:	potable: l.p-1.d-1	155
	rain and grey: l.p-1.d-1	5
	total: l.p-1.d-1	160

Benchmark performance of Drawn Study 4

Drawn Study Four

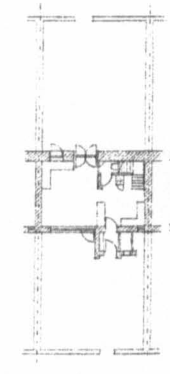
The conceptual structure of the dwelling is based upon the traditional wide frontage village terraced dwelling. The terrace is conceived of as a number of individual shells standing in close proximity, each capable of being adapted to reflect the needs of different lifestyles.

The structure of the urban grain proposed wide frontage dwellings in short runs of terraces. The width of the dwellings reflects the wide frontages endemic of traditional Yorkshire villages. An issue for the design of the dwelling became how to facilitate the individuation of space within the overall harmony of a row. Therefore the rows are conceived of as individual shells standing in close proximity. These shells are capable of customisation to the specific needs of different lifestyles, and of adapting to respond to those needs changing over time.

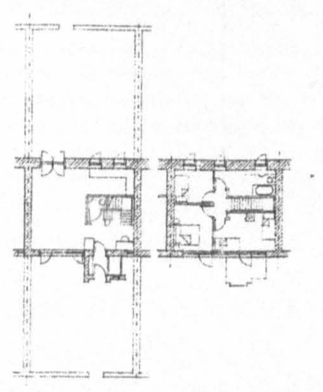
To achieve the diversity desired within the grain, and to establish a micro-climate, the masterplan required that dwellings face four different orientations. This presented challenges in maximising the utilisation of passive solar gain and sunlight penetration into the dwelling. To resolve this, a range of dwelling types were created that vary both in size and in their principal orientation; the variety of permutations available contributes further to the diversity of the overall grain. 12 dwelling types of 3 different sizes, responding to the 4 orientations of the urban grain are proposed. These are based upon a notional two-bedroom dwelling, a notional three-bedroom dwelling and a notional four-bedroom dwelling.

To reduce the problem of noise transmission between dwellings, a shortcoming frequently associated with terraces, each party wall is composed of two independent leaves. Therefore this embodies the conceptual structure of the dwelling as individual units, standing in very close proximity so as to appear as a row.

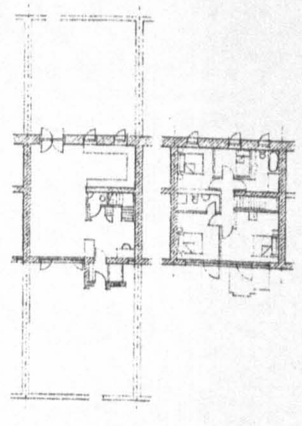
Immediately within the entrance to each dwelling, beyond the draught lobby, is a large entrance hall. This is also intended as a small study space. Beyond this, within the notional layouts proposed, circulation spaces are kept as small as possible in order to maximise the habitable space within the dwelling. The brief demanded the minimisation of domestic waste, and that the reduction of landfill waste should be considered. Therefore at the front of each dwelling, integrated into the porch, is a storage space with the capacity for two 'wheelie bins'. One bin is allocated for domestic refuse, whilst the other is allocated for all recyclable materials.



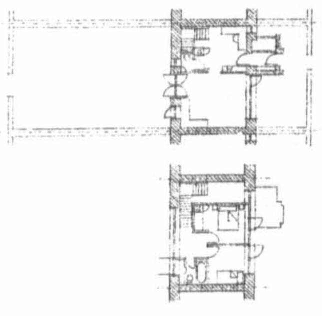
South facing notional '2 bedroom' dwelling, 1:200



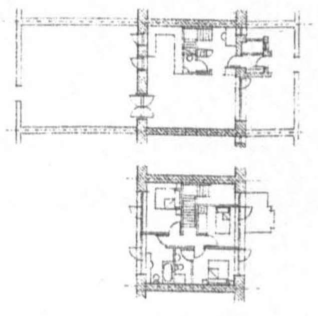
South facing notional '3 bedroom' dwelling, 1:200



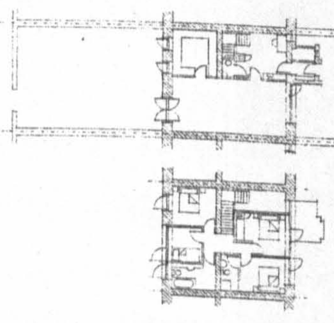
South facing notional '4 bedroom' dwelling, 1:200



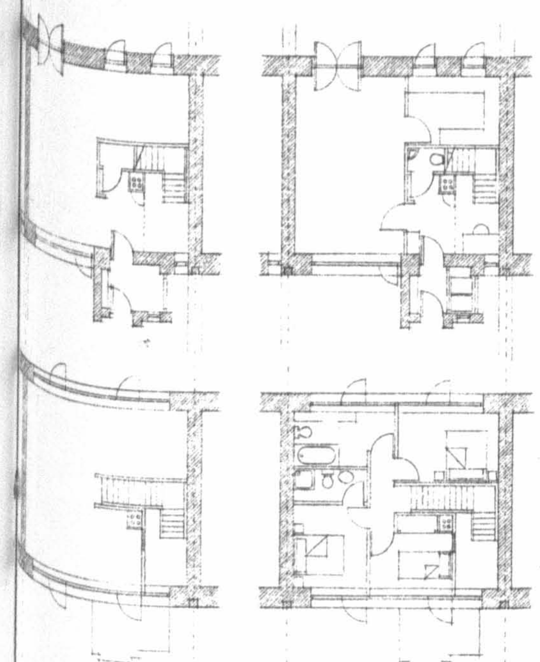
East facing notional '2 bedroom' dwelling, 1:200



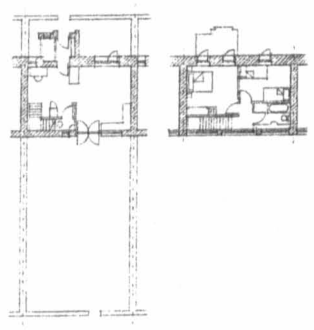
East facing notional '3 bedroom' dwelling, 1:200



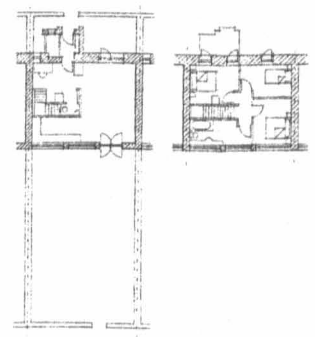
East facing notional '4 bedroom' dwelling, 1:200



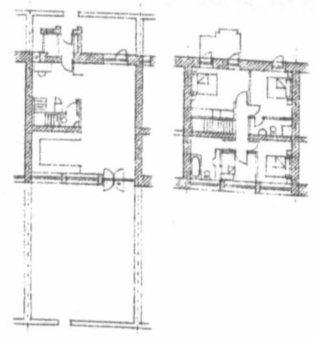
Shell and potential fit out as notional '4 bedroom' dwelling, 1:200



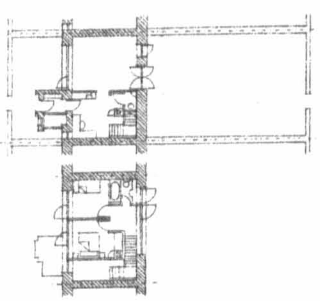
North facing notional '2 bedroom' dwelling, 1:200



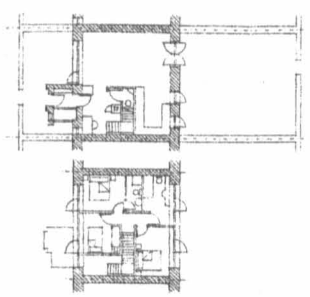
North facing notional '3 bedroom' dwelling, 1:200



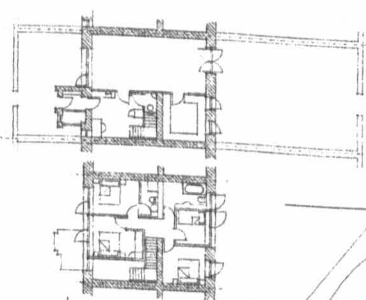
North facing notional '4 bedroom' dwelling, 1:200



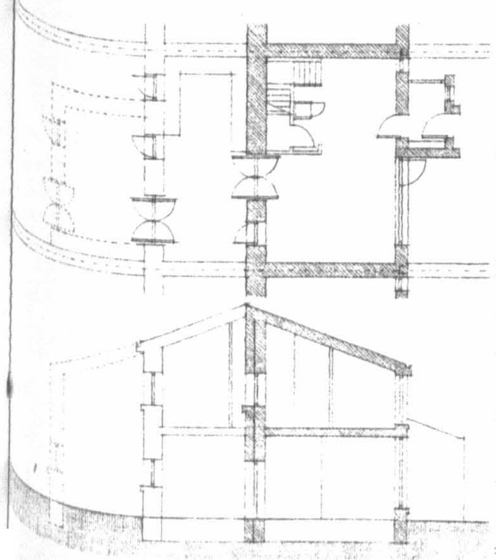
West facing notional '2 bedroom' dwelling, 1:200



West facing notional '3 bedroom' dwelling, 1:200



West facing notional '4 bedroom' dwelling, 1:200

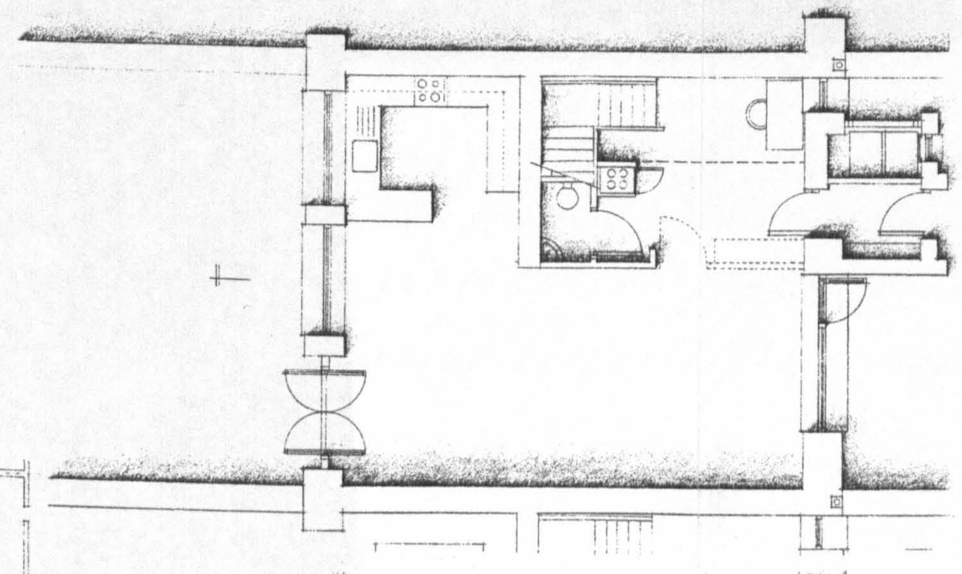


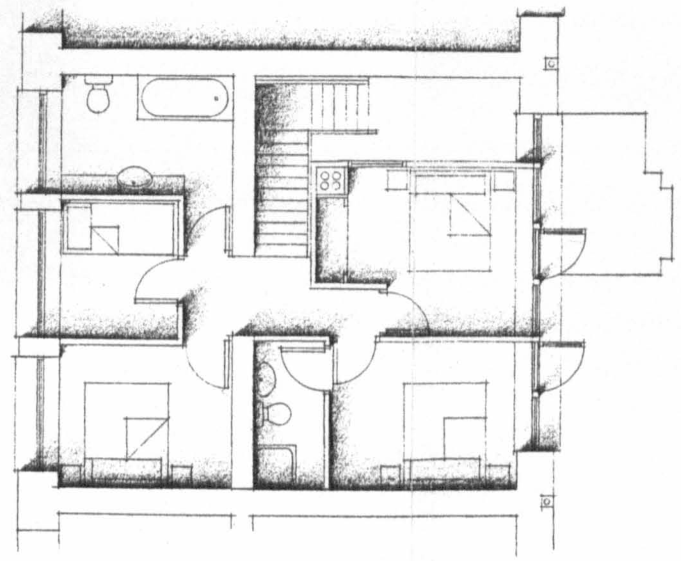
Expandability of notional '2 bedroom' dwelling into '4 bedroom' and beyond

Front elevation, 1:50

East facing notional '4 bedroom' dwelling

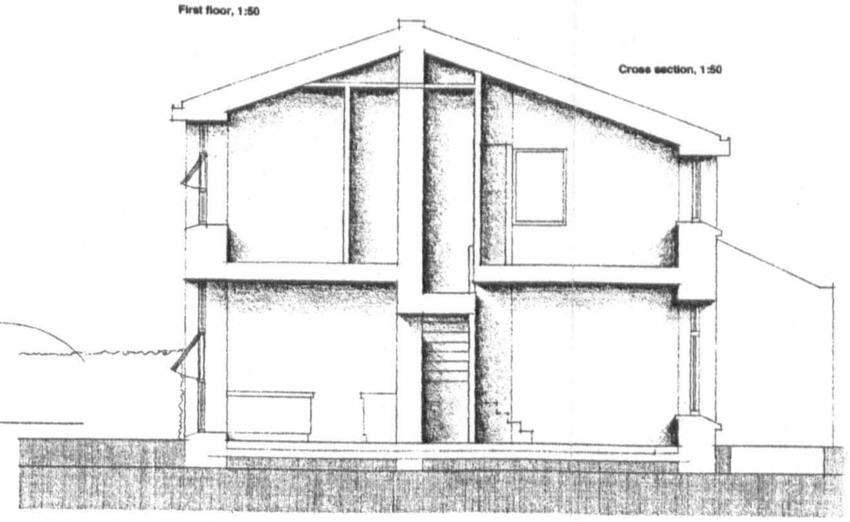
Ground floor, 1:50

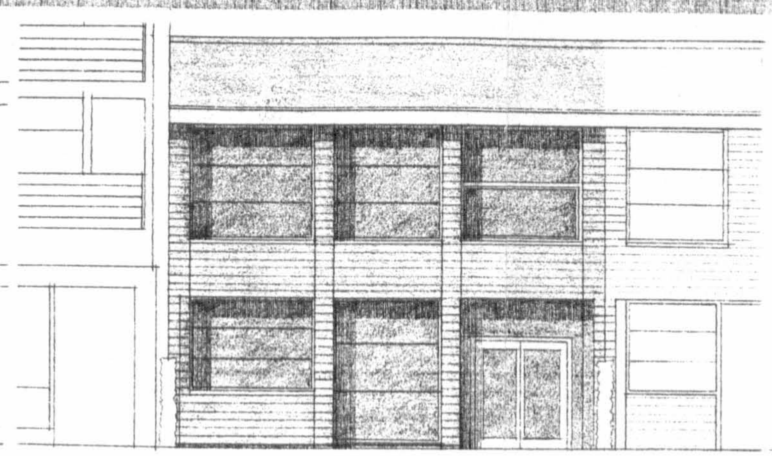




First floor, 1:50

Cross section, 1:50





Rear elevation, 1:50

Allerton Bywater: Scale of the Dwelling

Adaptability and Expandability

Conceptually each generic dwelling is conceived of as a structural shell, within which a prospective owner could particularise the interior to suit a lifestyle. The dwellings are also expandable, so that additional space can be added in a way that harmonises with the existing dwellings.

The term 'notional' to describe the size of the dwelling is intentional. The decision was made to minimise the number of internal load-bearing partitions. Conceptually each dwelling is conceived of as a structural shell, within which a prospective owner would be able to create and interior that suits a particular lifestyle. This would both maximise choice in the initial layout, to suit the initial inhabitants' preferences, and the potential adaptability of the dwelling over time. It is also proposed that the construction technology used to build the dwelling in the first instance will facilitate in expanding it at a later date. Thereby an extension will integrate and harmonise with the surrounding built form, as opposed to appearing as an ad-hoc addition. This potential for expanding the dwelling is integrated into the design of the initial dwellings. For example, the cross-section of the two-bedroom dwelling, probably the most likely to be extended, replicates the front portion of the cross-section of the four-bedroom dwelling; therefore simply adding a mono-pitch roof can convert the former type into the latter. The ability of the dwelling to respond to changing needs is one way in which the life span of the dwelling is maximised, to increase the efficiency of the materials and energy embodied within it.

Materiality

The different materiality of the exterior of the dwellings is another way in which the diversity of the urban grain is increased. It changes to provide increasing informality, from the sandstone of the streets, through the lanes, to the interior of the quadrants. This also provides orientation as people move through the grain.

The materiality of the urban grain has layers that articulate movement from the relative formality of the street front, inwards via lanes, toward the more informal interior of each quadrant. This variation in materiality is a way in which the diversity of the overall plan is increased, creating different identities within the different parts of the plan that can orientate people as they move through it. On the street frontages the predominant material is traditional Yorkshire sandstone; as one moves to the less formal edges of the blocks this becomes terracotta; moving through the lanes toward the informal interiors of the quadrants, which surround the allotments and park, render and timber are prevalent.

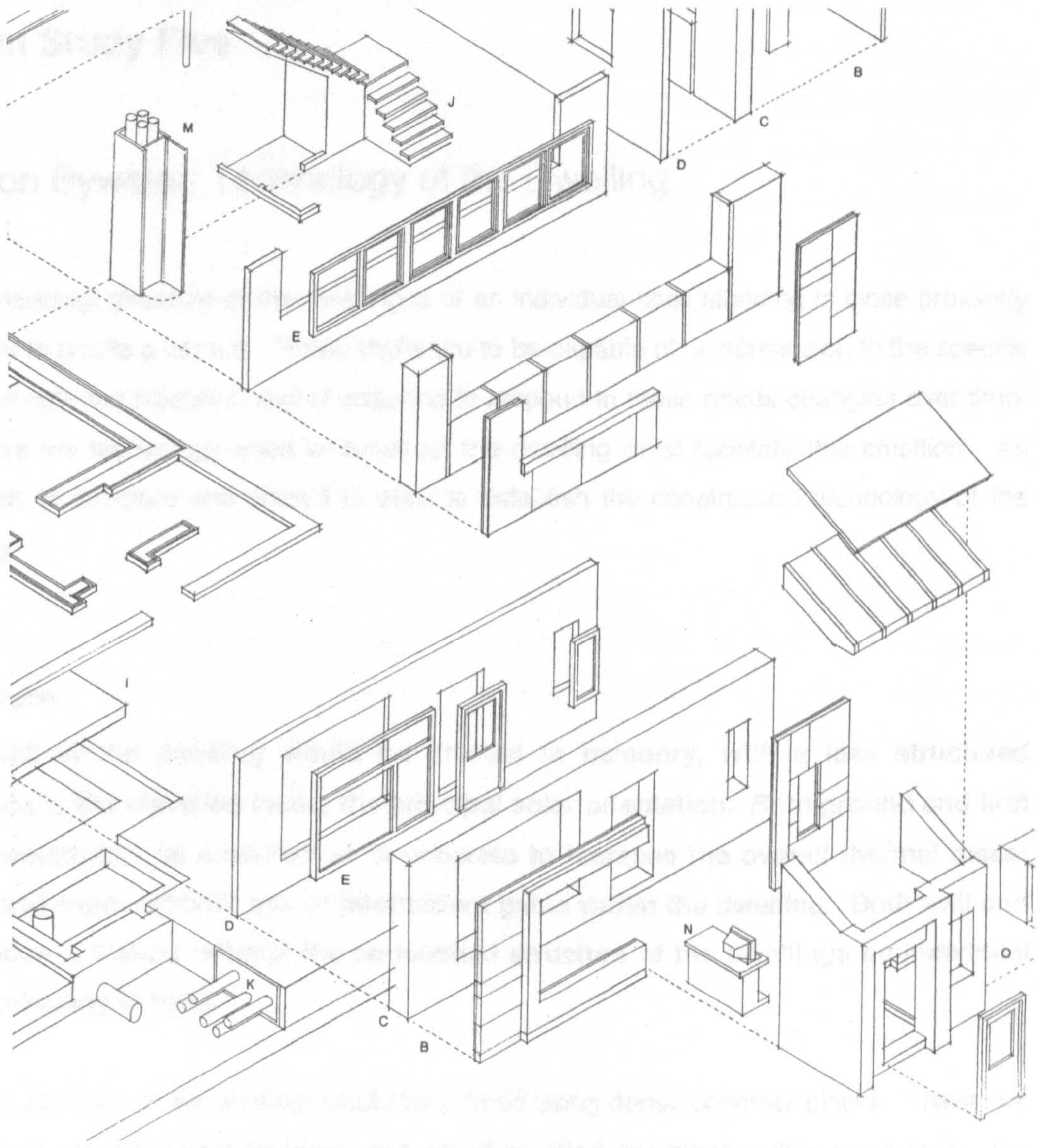
Space Standards

The specific intention was made to increase both the area and the habitable volume of the dwelling over that of the typical product of a national house builder, to improve its desirability. Subsequently this became one of the criteria of the 'urban house in paradise'.

Extensive analysis of the products of a national house builder and a national housing association was undertaken to establish the current standards from which to propose a benchmark increase. The space standards analysis also studied the percentage of space use, as an indicator of spatial preferences in new housing. The benchmark was set at an average increase of 10 percent for the area and 35 percent for the volume. The latter is achieved in part by utilising the roof pitch to maximise the ratio of inhabited space to enclosed space. In addition the floor to ceiling height of the ground floor is set at 3.0 metres.

Criteria		Benchmarks
		Allerton Bywater: Dwelling
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		Assessed in Drawn Study 5
CO2 emissions: On Site Construction Processes: kgCO2.m-2		Assessed in Drawn Study 5
Carbon intensity: kg.kWh-1		Assessed in Drawn Study 5
Construction period: weeks per dwelling		4
Contextual significance of site: Qualitative		Assessed in Drawn Study 5
Deconstruction and demolition: Recycling materials: Percent		Assessed in Drawn Study 5
Design life span: Years		100
Density	quantitative: p.ha-1	Assessed in Drawn Study 5
	qualitative	Assessed in Drawn Study 5
Diversity: programmes.ha-1		Assessed in Drawn Study 3
Domestic waste	inshore: kg.p-1.wk-1	4.8
	recycled: kg.p-1.wk-1	4.8
Ecological significance of the site: Percent and qualitative		Assessed in Drawn Study 3
Ecological weight: embodied energy: kWh.m-2		Assessed in Drawn Study 5
Ecological weight: CO2 emissions: kgCO2.m-2		Assessed in Drawn Study 5
Energy consumption: construction: kWh.m-2		Assessed in Drawn Study 5
Energy consumption: inhabitation: kWh.m-2.a-1		Assessed in Drawn Study 5
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study 5
Green space: Percent		Assessed in Drawn Study 3
Lifecycle cost	Construction: £.m-2.a-1	5.08
	Energy: £.m-2.a-1	7.76
	Water: £.p-1.a-1	380.54
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study 5
Other ecological impacts of materials: Qualitative, g.kWh-1		Assessed in Drawn Study 5
Other greenhouse gas emissions: g.kg-1		Assessed in Drawn Study 5
Pollution: energy consumption inhabitation: g.kWh-1		Assessed in Drawn Study 5
Procurement strategy: Qualitative		Assessed in Drawn Study 3
Quality of internal environment	indoor pollution: Qualitative	Assessed in Drawn Study 5
	daylight, living, kitchen, beds: Percent	Assessed in Drawn Study 5
	ventilation: ac.h-1	Assessed in Drawn Study 5
	airtightness: ac.h-1 at 50 Pa	Assessed in Drawn Study 5
Recycling construction waste: Percent		Assessed in Drawn Study 5
Adaptability: internal loadbearing walls: internal walls		0
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	Not Applicable
	3 persons: m2.p-1	Not Applicable
	4 persons: m2.p-1	19.9
	5 persons: m2.p-1	18.8
	6 persons: m2.p-1	Not Applicable
	7 persons: m2.p-1	20.7
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
	4 persons: m3.p-1	50.3
	5 persons: m3.p-1	57.6
	6 persons: m3.p-1	Not Applicable
	7 persons: m3.p-1	60.9
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance	Roof: W.m-2.K-1	0.14
	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	2.00
	Opaque outer doors: W.m-2.K-1	3.00
Use of recycled materials: Percent		Assessed in Drawn Study 5
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Assessed in Drawn Study 5
Water consumption: inhabitation	potable: l.p-1.d-1	100
	rain and grey: l.p-1.d-1	5
	total: l.p-1.d-1	160

Drawn Study Five



Allerton Bywater: Technology of the Dwelling

Drawn Study Five

Allerton Bywater: Technology of the Dwelling

The conceptual structure of the dwelling is of an individual shell standing in close proximity to others to create a terrace. These shells are to be capable of customisation to the specific needs of different lifestyles, and of adapting to respond to those needs changing over time. Therefore the technology used to construct the dwelling must facilitate this ambition. An approach of structure and shroud is used to establish the construction technology of the dwelling.

Structure

The shell of the dwelling would be created in masonry, with a less structured approach to the elevation facing the principal solar orientation. Both ground and first floors would also be constructed in concrete to increase the overall thermal mass; this would make efficient use of intermittent gains within the dwelling. Both wall and foundation structure reflects the conceptual structure of the dwellings as individual shells standing in rows.

The wall structure of the dwelling would be formed using dense concrete blocks. These are larger than can be moved by hand, and would be lifted into place with a small crane; the advantage of this technology is that the rate of construction would be significantly increased. To achieve structural stability, as there is no cavity, the blocks would be bonded together with an epoxy resin, as opposed to resting on mortar. This is a technology that is currently being used in the Netherlands. To create isolation, in response to the conceptual structure of independent shells in close proximity, the party walls would be composed of two leaves that are fully independent of each other, with insulation between to minimise acoustic transmissions between dwellings. Using blocks much larger than the traditional brick or concrete block would increase the rate of construction significantly. The shell of the dwelling is conceived of as solid around three sides with the face orientated toward the sun, either south or east depending upon the dwelling type, being more open and less structured, both literally and, as a design concept, metaphorically.

The concrete walls would create a high thermal mass within the structure of the dwelling. This is intended to reduce the energy consumption of the dwelling during inhabitation. After an initial 'warm up' period, the concrete structure would absorb incidental gains during the day, such as passive solar gain and metabolic gains if the dwelling is occupied, and release them when the dwelling cools down. With sufficient mass, the absorption and release of heat can occur on a seasonal as well as diurnal cycle, so that heat stored in summer is released into the dwelling during autumn and winter. To increase the thermal mass further, concrete floors would be used as opposed to the traditional use of timber floor in this type of dwelling. A concrete slab forms the ground floor and concrete beam and blocks the upper floor. The upper floor would be covered with a layer of screed, as would be the ground floor, to reduce the infiltration of air within the dwelling.

However, the extensive use of the concrete to create a high thermal mass has a disadvantage in terms of the quantity of embodied energy in the dwelling. The benchmarks show that the dwelling has an embodied energy level of 640.6 $kWh.m^{-2}$, in comparison with Szokolay's value for the 'typical' dwelling of 1,000 $kWh.m^{-2}$,[1] and the 'urban house in paradise' benchmark of 250 $kWh.m^{-2}$. This would have the same effect, in relative terms, on the level of embodied CO_2, which was calculated as 262.6 $kgCO_2.m^{-2}$. However, the local manufacture of prefabricated elements may reduce the values for these criteria. This would have the dual benefit of reducing the embodied energy of the dwelling, as less energy is consumed in transportation because the material is transported straight to the site, rather than via the manufacturing plant, and also creating employment within the local area, contributing to the socio-economic sustainability of Allerton Bywater.

The dwellings would be located upon a granular capping layer, a result of the remediation of the brownfield site. Therefore the recommended foundation strategy is a raft.[2] Following the concept of the dwellings as shells within a row, the rafts would be individual to each dwelling. This would allow for differential settlement between the dwellings that might occur as a consequence of displacement within the capping layer. Ideally the foundations for expanding a dwelling, for example from notional two-bedroom into notional four-bedroom, would be laid during the initial construction of the dwelling.

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[1] Refer to Ecological Weight: Embodied Energy criterion, in Annexe 3.13.
[2] Ralph Brade of Ove Arup, at Design Team Meeting on 18 January 2001.

Shroud

Surrounding the generic structure of the dwelling a rainscreen cladding is used to shroud the shell in a predetermined palette or materials, to create the desired material diversity within the urban grain. The performance of the overall envelope exceeds regulatory requirements. The proportions of the elevation are based upon a 900 mm module.

300 mm of non-CFC or HCFC blown foam insulation would be fixed back to the exterior face of the concrete walls. A rainscreen cladding, hung from a timber framework, would protect the insulation. In this way a basic technology can be used to shroud the generic structure of the dwelling in a predetermined palette or materials, of stone, render, timber and terracotta, to create the desired material diversity within the urban grain. The general thermal performance of the external envelope is 0.14 $W.m^{-2}.K^{-1}$; the value for windows would be higher than could be achieved by triple glazed units, as double glazed windows were considered by the Aire Design team as more economically viable in terms of additional capital cost against energy cost. However, all of the elements are an improvement, the majority to a significant extent, upon current regulatory standards. A proportional system was used to generate the overall harmony of the plan and elevations. This is based upon 2.7, 5.4 and 8.1 metres, with a 900 mm unit to integrate with the modularisation of the dwelling, and to facilitate prefabrication.

The roof is formed at an angle of 20 degrees. This pitch allows an increase in the inhabited volume of the dwelling, by expanding it into the roof void, but would not create a large space that consumes a significant quantity of energy in heating it. As the inhabited volume of the dwelling would be increased through including the space under the pitch within the inhabited space of the dwelling, gang-nail trusses would not be appropriate. To accommodate 300 mm of cellulose fibre insulation within the roof, timber I-section beams are proposed, at 600 mm centres; timber noggins give these lateral bracing, and prevent the insulation sinking to the eaves and therefore reducing the thermal performance of the roof at its apex.[3] Plywood panels top and bottom mean that the roof is a stressed skin unit, and therefore could be prefabricated in close proximity to the site. The timber structure of the roof would be linked to the timber frame of the rainscreen, both with insulation between, and to the insulation below the floor slab, to create a continuous layer around the dwelling.

[3] A similar technology is used by Robert and Brenda Vale for their dwelling in Southwell, from where this technology for the roof is adopted. Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.

It was estimated by the construction consultant for Aire Design that through the use of prefabricated components and elements, the dwelling could be constructed at three times the typical rate of the national house builder, equating to a construction period per dwelling of 4 weeks.[4] The rapid construction of the shell means that a weather-tight structure could be created very quickly, and the subsequent fit-out activities would be able to take place within a dry environment.

Material Sustainability

A lifecycle approach to the sustainability of the dwelling has been taken. Therefore the selection of materials was based upon their embodied energy, other ecological impacts of their extraction and manufacture, and their role in the energy consumption in the dwelling once it is occupied.

The sustainability of materials has also been considered. Wherever possible recycled aggregates would be used within the concrete that creates the structural shell of the dwelling, and also in the sub base for roads and pathways. The glazing and doorways would be formed using timber frames, as opposed to uPVC. The use of durable managed softwood, which is a renewable resource, would be preferable to uPVC which, although it can be recycled, creates more environmental damage in its production than timber.[5] Furthermore, materials would be used that have a rating of 'A', the highest achievable, under the Building Research Establishment's *Green Guide to Housing Specification*.[6]

The potential adaptability of the interior of the dwelling, which is conceived of as a shell, also had to be reflected in the proposed servicing. As all of the internal walls would be capable of being removed, permanent services could not be contained within them. Therefore a concept of 'wet walls' was developed. A recess would be built into the shell of the dwelling at either side. Within this recess water and waste pipes can service the kitchen and bathroom of the dwelling, and allow for the potential relocation of these spaces. Cabling would be carried within skirting ducts, which can be relocated as partitions are removed. It

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[4] Personal communication with Tony Rimmer of Aire Design, 3 March 1999.
[5] Anink, David, Cheil Boonstra and John Mak. *Handbook of Sustainable Building - An Environmental Preference Method for Selection of Materials for Use in Construction and Refurbishment*, London: James & James, 1996,

is envisaged that services leading to the dwelling would be contained within a single duct, through an integrated approach to electricity, telecommunications, gas and other utilities.

Occupational Sustainability

The brief demanded that energy consumption during occupation be reduced by 50 percent from that of a typical dwelling; the predicted consumption has been estimated as 10 percent that of a dwelling built to current regulations. Other impacts of the period of inhabitation have also been considered, over and above the contribution of adaptability and expandability highlighted elsewhere.

The energy consumed during the period of inhabitation can account for between 85 and 90 percent of the total energy consumed in the life span of the dwelling, from material extraction through occupation to demolition; therefore it is a significant priority in the overall sustainability of the dwelling. The rate of energy consumed in maintaining a constant internal temperature is dependent upon the performance of the fabric in restricting the flow heat through the external envelope, the strategy for which is outlined above, and restricting the uncontrolled penetration of cold external air into the dwelling.

As the thermal insulation of the fabric increases, the infiltration of cold air becomes increasingly significant to the energy consumption; the research has demonstrated that at levels of best practice the infiltration can be almost three times as significant as thermal performance in improving the ecological sustainability of the dwelling. An infiltration target of 2.0 $ac.hr^{-1}$ at 50 Pa was proposed. This would be achieved through the use of a polyethylene air barrier in the roof, wet plaster on the walls would be skimmed right down to the screed on the floor slabs to form a continuous surface, rather than stopping just below skirting level. The window openings would be formed with a plywood surround; a non-CFC foam sprayed between the back of the window frame and the plywood surround and silicone sealant between the plywood and the interior of the wall would seal these elements into the external envelope. The use of concrete throughout the dwelling, as opposed to using a timber floor hung from a concrete wall, would reduce the chance of cracks forming as a result of differential shrinkage or movement which can lead to unintentional air infiltration.

[6] Anderson, Jane and Nigel Howard. *The Green Guide to Housing Specification – An Environmental Profiling System for Building Materials and Components*, London: Construction Research Communications Limited, 2000.

With a high level of thermal insulation, high thermal mass and a relatively air tight structure, a conventional heating system, such as gas central heating with radiators, would be oversized and therefore inefficient. The adequate ventilation of the interior spaces to maintain a comfortable, healthy environment might also be problematic. Warm air mechanical ventilation with heat recovery was proposed to resolve this, and to reduce internal pollution and ensure an adequate supply of fresh air within an airtight structure. The Genvex unit originated in Denmark; it can provide both domestic hot water and a supply of fresh air that is reheated to roughly room temperature. Additional heating, if required, could be provided by electric heating elements in the supply ducts. A constant supply of warm air throughout the dwelling would reduce the probability of condensation and overly high air humidity.

The competition brief demanded that the energy consumption of the dwelling be reduced to 50 percent of the consumption of a typical dwelling.[7] The benchmarking process has established that a dwelling built to current standards would consume 194 $kWh.m^{-2}.a^{-1}$, of which 148 $kWh.m^{-2}.a^{-1}$ would be attributable to space and water heating.[8] The predicted energy consumption of the Drawn Study dwelling for space and water heating, calculated using the Standard Assessment Procedure worksheet, was 15 $kWh.m^{-2}.a^{-1}$. This was a 90 percent reduction over the performance of a typical dwelling. Estimates for the energy consumption from other sources were added to this, using scenarios of efficiency comparable to that achieved for space and water heating. This would equate to a total energy consumption for the dwelling of 41 $kWh.m^{-2}.a^{-1}$.[9] As all of this energy is assumed to be electricity, this would have a consequential gross CO_2 emission of 23.9 $kgCO_2.m^{-2}.a^{-1}$.

The harvesting of rainwater has also been integrated into the dwellings, although it is not proposed for use within the dwelling. An individual tank supplies water for external consumption, such as watering the garden or washing a car, which would otherwise have used water that is drinkable, the purification of which consumes energy and fossil fuels and therefore produces pollution. In a typical dwelling with four inhabitants, this provision would save 140 litres of water per week.

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[7] English Partnerships, *Millennium Communities Competition - Allerton Bywater Stage Two Development Brief*, 1998.

[8] Refer to Annexe 3.16, Energy Consumption: Inhabitation.

[9] This scenario is based upon the 'zero heating' standard proposed in *GIR 53*. The total value can be attributed to 2,100 $kWh.a^{-1}$ due to lighting and appliances, 330 $kWh.a^{-1}$ due to cooking and 200 $kWh.a^{-1}$ due to pumps and fans from the mechanical ventilation. This annual total is divided across the floor are of the dwelling. BRECSU. 'Building a Sustainable Future – Homes for an Autonomous Community', *General Information Report Number 53*, London: HMSO, October 1998.

The performance of the Drawn Study in terms of the full criteria of the 'urban house in paradise' can be seen in the table overleaf.

Criteria		Benchmarks
		Allerton Bywater: Technology of Dwelling
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		23.9
CO2 emissions: On Site Construction Processes: kgCO2.m-2		34.6
Carbon intensity: kg.kWh-1		0.0
Construction period: weeks per dwelling		Assessed in Drawn Study 4
Contextual significance of site: Qualitative		Assessed in Drawn Study 3
Deconstruction and demolition: Recycling materials: Percent		50
Design life span: Years		Assessed in Drawn Study 4
Density:	quantitative: p.ha-1	Assessed in Drawn Study 3
	qualitative	Assessed in Drawn Study 3
Diveristy: programmes.ha-1		Assessed in Drawn Study 3
Domestic waste:	refuse: kg.p-1.wk-1	Assessed in Drawn Study 4
	recycled: kg.p-1.wk-1	Assessed in Drawn Study 4
Ecological significance of the site: Percent and qualitative		Assessed in Drawn Study 3
Ecological weight: embodied energy: kWh.m-2		640.6
Ecological weight: CO2 emissions: kgCO2.m-2		262.6
Energy consumption: construction: kWh.m-2		96.1
Energy consumption: inhabitation: kWh.m-2.a-1		41.0
Energy generation: kWh.m-2.a-1		0.0
Green space: Percent		Assessed in Drawn Study 3
Lifecycle cost:	Construction: £.m-2.a-1	Assessed in Drawn Study 4
	Energy: £.m-2.a-1	Assessed in Drawn Study 4
	Water: £.p-1.a-1	Assessed in Drawn Study 4
Nitrogen oxide emissions: mg.kWh-1		0.0
Other ecological impacts of materials: Qualitative, g.kWh-1		A
Other greenhouse gas emissions: g.kg-1		0.0
Pollution: energy consumption inhabitation: g.kWh-1		6.494
Procurement strategy: Qualitative		Assessed in Drawn Study 3
Quality of internal environment:	indoor pollution: Qualitative	Yes
	daylight: living, kitchen, beds: Percent	4.6, 1.9, 3.4
	ventilation: ac.h-1	0.6
	airtightness: ac.h-1 at 50 Pa	2.0
Recycling construction waste: Percent		5.0
Adaptability: Internal loadbearing walls: Internal walls		Assessed in Drawn Study 4
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	Not Applicable
	3 persons: m2.p-1	Not Applicable
	4 persons: m2.p-1	Assessed in Drawn Study 4
	5 persons: m2.p-1	Assessed in Drawn Study 4
	6 persons: m2.p-1	Not Applicable
	7 persons: m2.p-1	Assessed in Drawn Study 4
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
	4 persons: m3.p-1	Assessed in Drawn Study 4
	5 persons: m3.p-1	Assessed in Drawn Study 4
	6 persons: m3.p-1	Not Applicable
	7 persons: m3.p-1	Assessed in Drawn Study 4
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance:	Roof: W.m-2.K-1	Assessed in Drawn Study 4
	Exposed walls: W.m-2.K-1	Assessed in Drawn Study 4
	Ground and exposed floors: W.m-2.K-1	Assessed in Drawn Study 4
	Windows and rooflights: W.m-2.K-1	Assessed in Drawn Study 4
	Opaque outer doors: W.m-2.K-1	Assessed in Drawn Study 4
Use of recycled materials: Percent		50
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		9.5
Water consumption: inhabitation:	potable: l.p-1.d-1	Assessed in Drawn Study 4
	rain and grey: l.p-1.d-1	Assessed in Drawn Study 4
	total: l.p-1.d-1	Assessed in Drawn Study 4

Benchmark performance of Drawn Study 5

Drawn Study Four

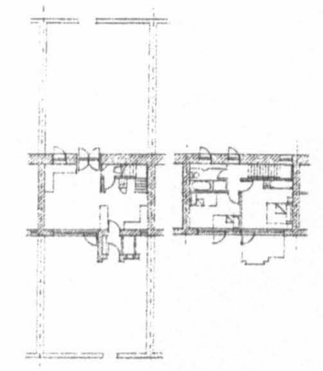
The conceptual structure of the dwelling is based upon the traditional wide frontage village terraced dwelling. The terrace is conceived of as a number of individual shells standing in close proximity, each capable of being adapted to reflect the needs of different lifestyles.

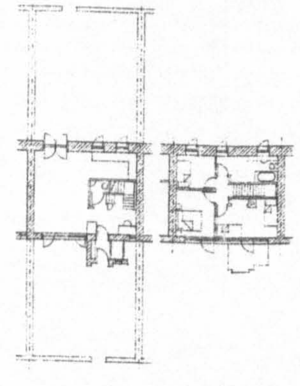
The structure of the urban grain proposed wide frontage dwellings in short runs of terraces. The width of the dwellings reflects the wide frontages endemic of traditional Yorkshire villages. An issue for the design of the dwelling became how to facilitate the individuation of space within the overall harmony of a row. Therefore the rows are conceived of as individual shells standing in close proximity. These shells are capable of customisation to the specific needs of different lifestyles, and of adapting to respond to those needs changing over time.

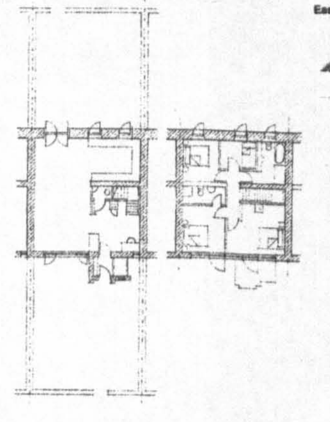
To achieve the diversity desired within the grain, and to establish a micro-climate, the masterplan required that dwellings face four different orientations. This presented challenges in maximising the utilisation of passive solar gain and sunlight penetration into the dwelling. To resolve this, a range of dwelling types were created that vary both in size and in their principal orientation; the variety of permutations available contributes further to the diversity of the overall grain. 12 dwelling types of 3 different sizes, responding to the 4 orientations of the urban grain are proposed. These are based upon a notional two-bedroom dwelling, a notional three-bedroom dwelling and a notional four-bedroom dwelling.

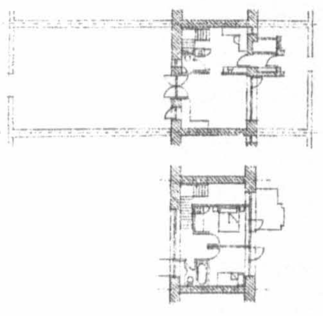
To reduce the problem of noise transmission between dwellings, a shortcoming frequently associated with terraces, each party wall is composed of two independent leaves. Therefore this embodies the conceptual structure of the dwelling as individual units, standing in very close proximity so as to appear as a row.

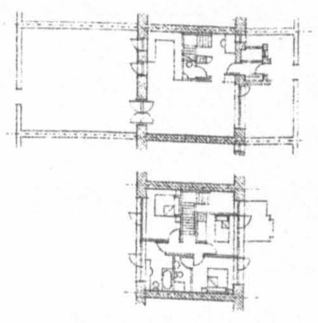
Immediately within the entrance to each dwelling, beyond the draught lobby, is a large entrance hall. This is also intended as a small study space. Beyond this, within the notional layouts proposed, circulation spaces are kept as small as possible in order to maximise the habitable space within the dwelling. The brief demanded the minimisation of domestic waste, and that the reduction of landfill waste should be considered. Therefore at the front of each dwelling, integrated into the porch, is a storage space with the capacity for two wheelie bins. One bin is allocated for domestic refuse, whilst the other is allocated for all recyclable materials.

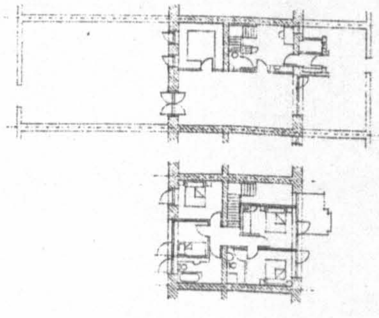

South facing notional '2 bedroom' dwelling, 1:200

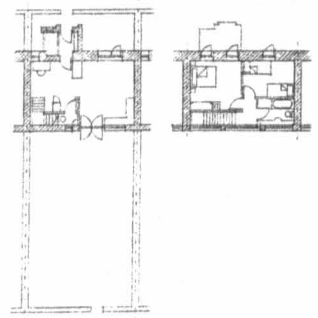

South facing notional '3 bedroom' dwelling, 1:200

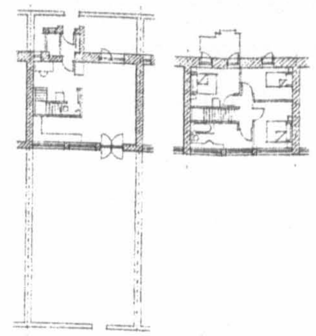

South facing notional '4 bedroom' dwelling, 1:200

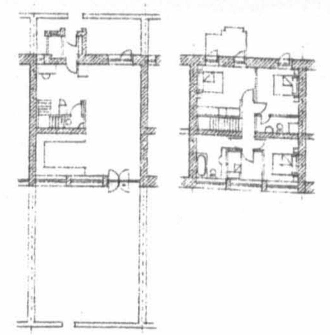

East facing notional '2 bedroom' dwelling, 1:200

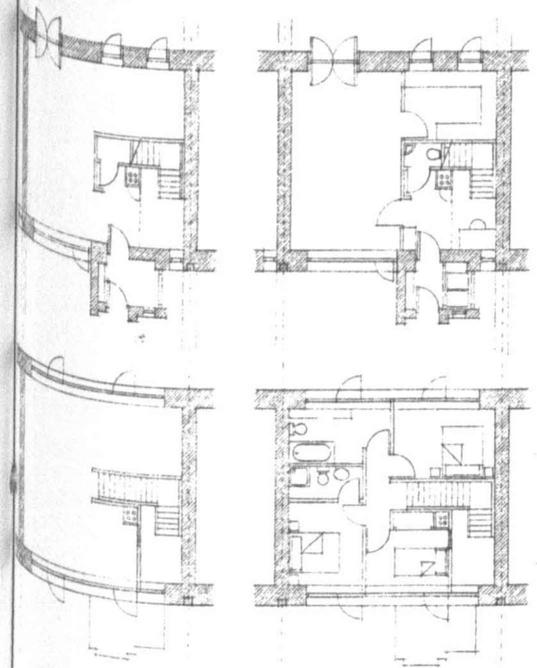

East facing notional '3 bedroom' dwelling, 1:200

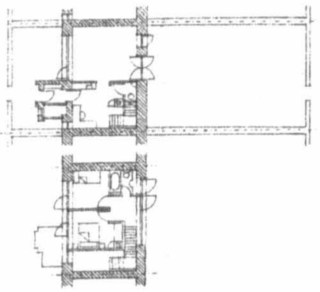

East facing notional '4 bedroom' dwelling, 1:200

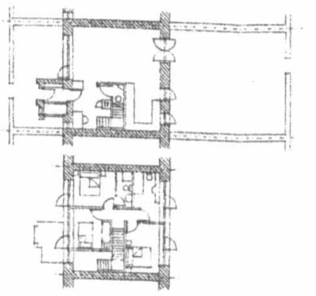

North facing notional '2 bedroom' dwelling, 1:200

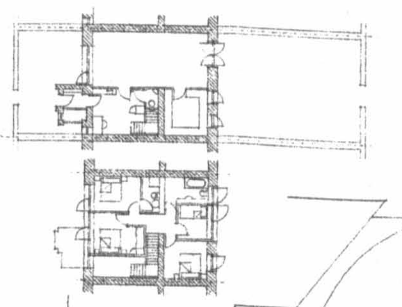

North facing notional '3 bedroom' dwelling, 1:200

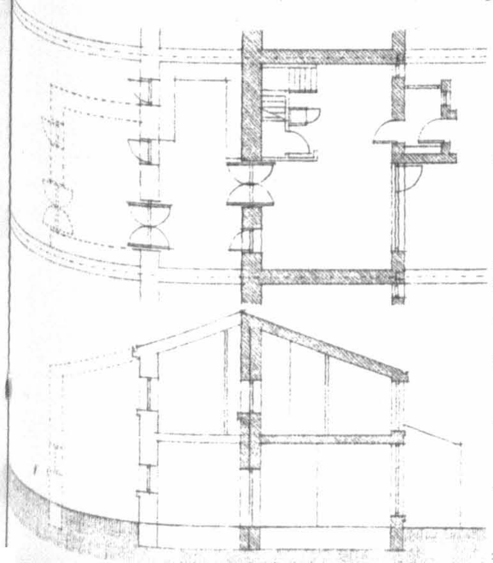

North facing notional '4 bedroom' dwelling, 1:200

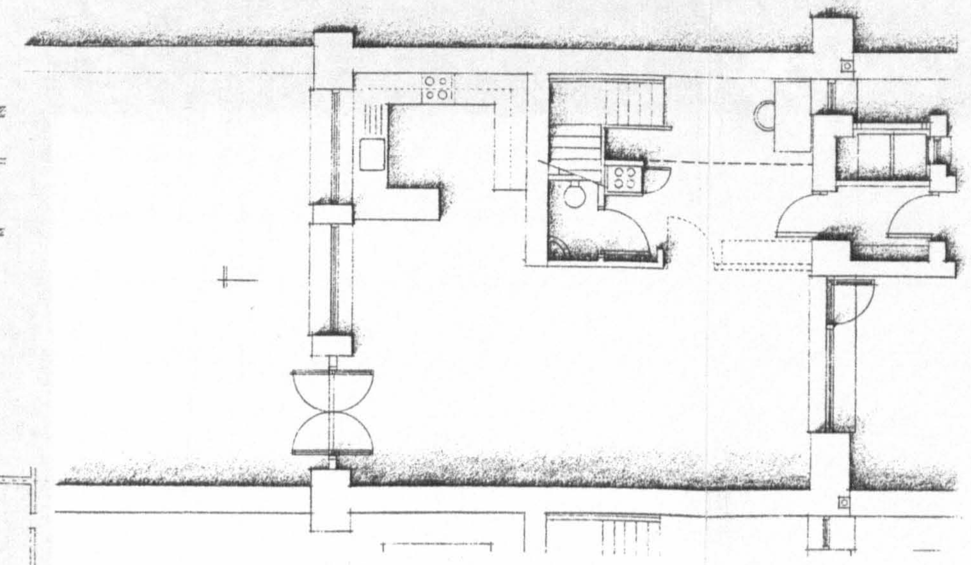

Shell and potential fit out as notional '4 bedroom' dwelling, 1:200


West facing notional '2 bedroom' dwelling, 1:200

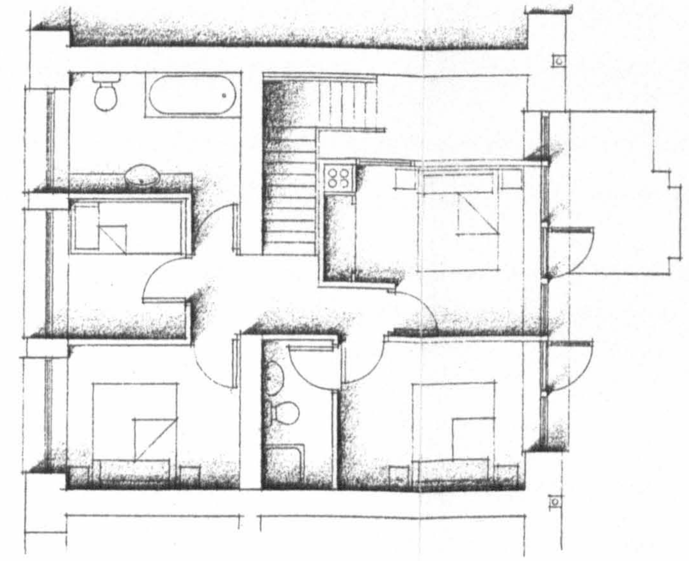

West facing notional '3 bedroom' dwelling, 1:200

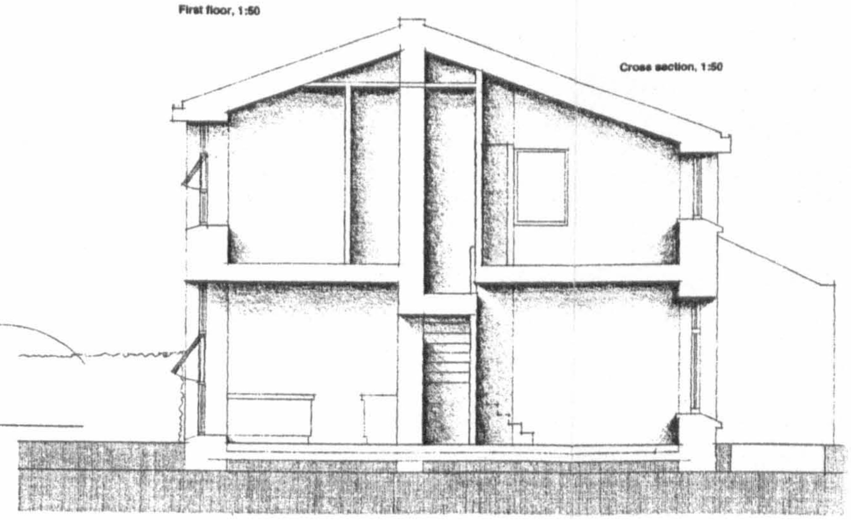

West facing notional '4 bedroom' dwelling, 1:200


Expandability of notional '2 bedroom' dwelling into '4 bedroom' and beyond

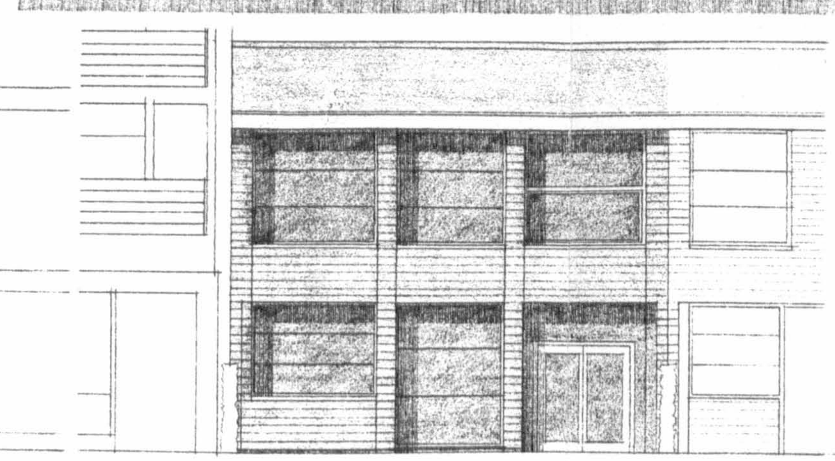

East facing notional '4 bedroom' dwelling

Ground floor, 1:50


First floor, 1:50


Cross section, 1:50


Front elevation, 1:50


Rear elevation, 1:50

Allerton Bywater: Scale of the Dwelling

Adaptability and Expandability

Conceptually each generic dwelling is conceived of as a structural shell, within which a prospective owner could particularise the interior to suit a lifestyle. The dwellings are also expandable, so that additional space can be added in a way that harmonises with the existing dwellings.

The term 'notional' to describe the size of the dwelling is intentional. The decision was made to minimise the number of internal load-bearing partitions. Conceptually each dwelling is conceived of as a structural shell, within which a prospective owner would be able to create and interior that suits a particular lifestyle. This would both maximise choice in the initial layout, to suit the initial inhabitants' preferences, and the potential adaptability of the dwelling over time. It is also proposed that the construction technology used to build the dwelling in the first instance will facilitate in expanding it at a later date. Thereby an extension will integrate and harmonise with the surrounding built form, as opposed to appearing as an ad-hoc addition. This potential for expanding the dwelling is integrated into the design of the initial dwellings. For example, the cross-section of the two-bedroom dwelling, probably the most likely to be extended, replicates the front portion of the cross-section of the four-bedroom dwelling; therefore simply adding a mono-pitch roof can convert the former type into the latter. The ability of the dwelling to respond to changing needs is one way in which the life span of the dwelling is maximised, to increase the efficiency of the materials and energy embodied within it.

Materiality

The different materiality of the exterior of the dwellings is another way in which the diversity of the urban grain is increased. It changes to provide increasing informality, from the sandstone of the streets, through the lanes, to the interior of the quadrants. This also provides orientation as people move through the grain.

The materiality of the urban grain has layers that articulate movement from the relative formality of the street front, inwards via lanes, toward the more informal interior of each quadrant. This variation in materiality is a way in which the diversity of the overall plan is increased, creating different identities within the different parts of the plan that can orientate people as they move through it. On the street frontages the predominant material is traditional Yorkshire sandstone; as one moves to the less formal edges of the blocks this becomes terracotta; moving through the lanes toward the informal interiors of the quadrants, which surround the allotments and park, render and timber are prevalent.

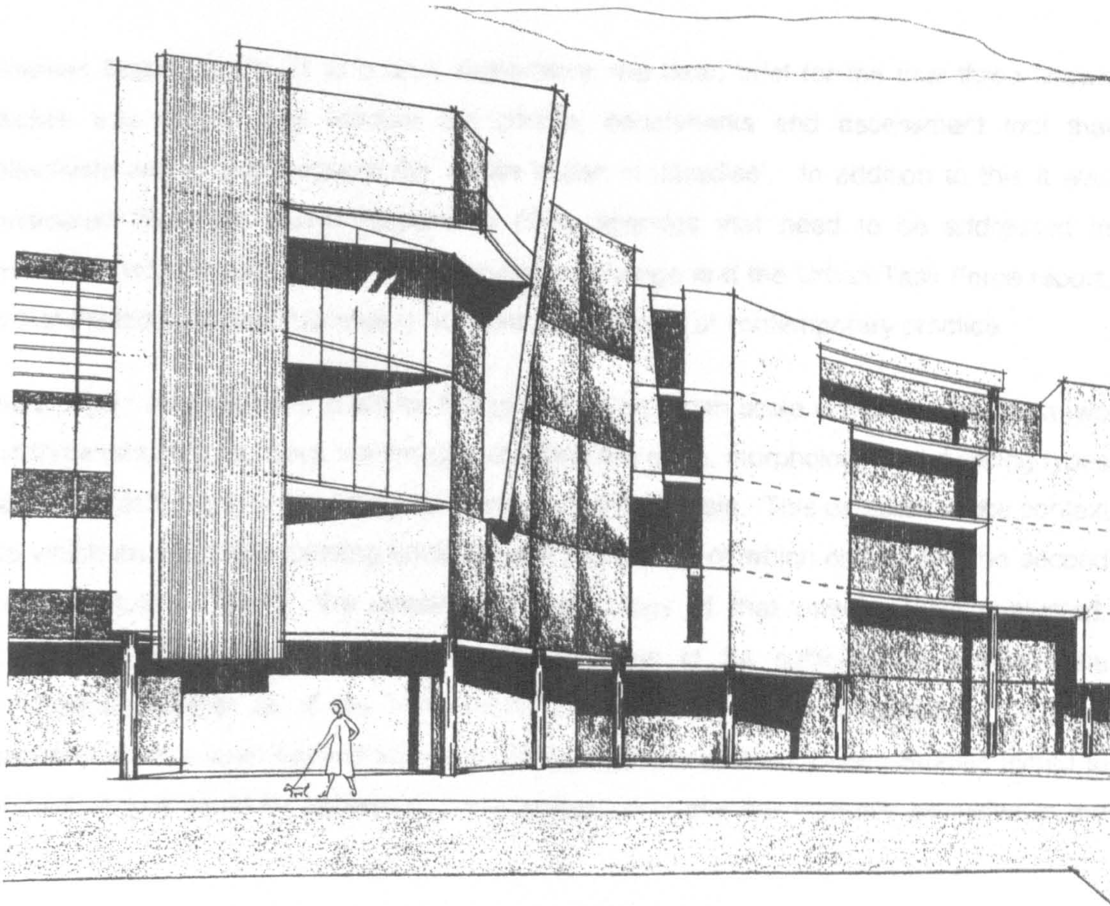
Space Standards

The specific intention was made to increase both the area and the habitable volume of the dwelling over that of the typical product of a national house builder, to improve its desirability. Subsequently this became one of the criteria of the 'urban house in paradise'.

Extensive analysis of the products of a national house builder and a national housing association was undertaken to establish the current standards from which to propose a benchmark increase. The space standards analysis also studied the percentage of space use, as an indicator of spatial preferences in new housing. The benchmark was set at an average increase of 10 percent for the area and 35 percent for the volume. The latter is achieved in part by utilising the roof pitch to maximise the ratio of inhabited space to enclosed space. In addition the floor to ceiling height of the ground floor is set at 3.0 metres.

Criteria		Benchmarks
		Allerton Bywater: Dwelling
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		Assessed in Drawn Study 5
CO2 emissions: On Site Construction Processes: kgCO2.m-2		Assessed in Drawn Study 5
Carbon intensity: kg.kWh-1		Assessed in Drawn Study 5
Construction period: weeks per dwelling		4
Contextual significance of site: Qualitative		Assessed in Drawn Study 5
Deconstruction and demolition: Recycling materials: Percent		Assessed in Drawn Study 5
Design life span: Years		150
Density	quantitative: p.ha-1	Assessed in Drawn Study 3
	qualitative	Assessed in Drawn Study 3
Diversity: programmes.ha-1		Assessed in Drawn Study 3
Domestic waste	refuse: kg.p-1.wk-1	4.8
	recycled: kg.p-1.wk-1	4.8
Ecological significance of the site: Percent and qualitative		Assessed in Drawn Study 7
Ecological weight: embodied energy: kWh.m-2		Assessed in Drawn Study 5
Ecological weight: CO2 emissions: kgCO2.m-2		Assessed in Drawn Study 5
Energy consumption: construction: kWh.m-2		Assessed in Drawn Study 5
Energy consumption: inhabitation: kWh.m-2.a-1		Assessed in Drawn Study 5
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study 5
Green space: Percent		Assessed in Drawn Study 3
Lifecycle cost	Construction: £.m-2.a-1	5.08
	Energy: £.m-2.a-1	7.76
	Water: £.p-1.a-1	380.54
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study 5
Other ecological impacts of materials: Qualitative, g.kWh-1		Assessed in Drawn Study 5
Other greenhouse gas emissions: g.kg-1		Assessed in Drawn Study 5
Pollution: energy consumption inhabitation: g.kWh-1		Assessed in Drawn Study 5
Procurement strategy: Qualitative		Assessed in Drawn Study 5
Quality of internal environment	indoor pollution: Qualitative	Assessed in Drawn Study 5
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 5
	ventilation: ac.h-1	Assessed in Drawn Study 5
	airtightness: ac.h-1 at 50 Pa	Assessed in Drawn Study 5
Recycling construction waste: Percent		Assessed in Drawn Study 5
Adaptability: Internal loadbearing walls: Internal walls		0
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	Not Applicable
	3 persons: m2.p-1	Not Applicable
	4 persons: m2.p-1	18.9
	5 persons: m2.p-1	16.8
	6 persons: m2.p-1	Not Applicable
	7 persons: m2.p-1	20.7
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
	4 persons: m3.p-1	50.7
	5 persons: m3.p-1	67.6
	6 persons: m3.p-1	Not Applicable
	7 persons: m3.p-1	60.9
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance	Roof: W.m-2.K-1	0.14
	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	2.00
	Opaque outer doors: W.m-2.K-1	3.00
Use of recycled materials: Percent		Assessed in Drawn Study 5
Use of renewable raw materials: Percent		Not Assessed
Utilisation of local resources: %		Not Assessed
Water consumption: construction: l.m-2		Assessed in Drawn Study 5
Water consumption: inhabitation	potable: l.p-1.d-1	150
	rain and grey: l.p-1.d-1	5
	total: l.p-1.d-1	160

Drawn Study Six



Ancoats: Scale of the Urban District and Site

Drawn Study Six

Ancoats: The Scale of the Urban District and Site

Whereas Drawn Studies 1 to 5 were exploratory, the basic brief for the final three Drawn Studies was to test and validate the criteria, benchmarks and assessment tool that collectively define and measure the 'urban house in paradise'. In addition to this it was considered that they should respond to other agendas that need to be addressed in developing urban housing, such as demographic change and the Urban Task Force report, so that the research methodology is not abstract to issues of contemporary practice.

There were three scales of study for this project. The urban scale is manifested into a two and three-dimensional block masterplan, studying the grain, morphology and dwelling types required to achieve the relevant benchmarks set by the thesis. This established the context into which an individual dwelling could be set, the design of which constituted the second scale of study. Thirdly, the construction technology of that dwelling was evaluated. Collectively the scope of these three Studies was to be sufficient to evaluate the performance against all of the benchmarks of the 'urban house in paradise'. As the benchmarks have been derived from a multitude of sources, these Drawn Studies aimed to establish if they could be achieved in one project, or if any are mutually exclusive to the others.

Because the primary aim of the study was to provide material against which to assess and validate the 'urban house in paradise' benchmarks and assessment tool, the focus of the work was on the latter two scales of study, which the tool is predicated toward. However, the urban scale was important on two levels: firstly in providing the context in which to create the dwelling, and secondly in validating the benchmarks of the tool that apply to the urban scale, such as density, green space and programmatic diversity.

Site

Five sites in Manchester were initially considered for the Drawn Study. The one selected is closest in proximity to the city centre, only a few minutes walk from Piccadilly Gardens, and has no discernible ecological value. A brownfield site, it is

partly occupied by existing buildings, some of which are derelict, and the remainder is currently used as a car park.

Five sites within Manchester were initially considered for the location of the final drawn studies. These were selected in consultation with the Planning Office of Manchester City Council, to ensure that they are appropriate to the city's unitary development plan. All five are located on the eastern side of the city, in varying degrees of proximity to the centre.

The first site considered was the closest to the city centre, in Ancoats. Five minutes walk from Piccadilly Gardens, it is also only a short walk from Piccadilly railway station, the city's national interchange. Existing buildings toward the city centre partially define the 11.6 hectares; boundaries to the remaining edges were identified through the existing topography and context. Some of the site is currently being utilised, and therefore would have to be phased into the development. A significant proportion of the site is vacant, and currently used as a car park. A canal bisects the site, which is one hundred percent brownfield. The use of the site as a car park has prevented the establishment of any vegetation.

At 15 hectares the Ardwick site is second largest and is slightly further, at twenty-five minutes walk, from the city centre. However, there is a railway station at its southern boundary, which is the first outside of Manchester Piccadilly, and a frequent bus service along Aston Old Road to the north of the site. There are also cycle lanes along some roads into the city centre. Therefore the site is served by sustainable modes of transport into the city. This is the site's only discernible attribute. To its detriment, although vacant there is a potential ecological value as the site is overgrown with vegetation. There are difficult edge conditions, as viaducts bound it around three sides. Surrounded by industrial units, there is a low degree of urbanity around the site, and very little residential context.

Further from the city centre is the former Jackson's brickworks. Although the site is evidently brownfield, it is also overgrown, and therefore has potential ecological value. The canal to the north edge is an evident attribute, and could provide a route for pedestrians and cyclists into the city; the nearest bus service is five minutes walk away. At 17.4 hectares it is also the largest site. There is some residential context, which is predominantly two storey semi-detached and terraced housing; therefore, although the City Council envisage a mixed function development on the site, it was considered inappropriate to a project predicated toward urban dwelling, and to the density benchmark.

The fourth and fifth sites are in close proximity to each other, and are a similar distance from the city centre as the third site. Bounded by three roads and a railway line, the fourth site was formerly railway sidings and a depot, any evidence of which has been erased. It was evident from the empirical study that all of the 7.69 hectares were brownfield land.

The final site considered was formerly Monsall hospital. The buildings on it had recently been demolished, and therefore the majority of the 13.3 hectare site fulfilled the criteria of brownfield land; some green space was included within the hospital's grounds. The context of the site is similar to that of the third site, with two storey semi-detached and terraced housing, and therefore is considered equally inappropriate; a secondary school bounds the site to the east. Although served by a bus route, but further from it than the fourth site, like the latter two sites considered above, it is remote from the city centre.

Having appraised the attributes and shortcomings of each of the five, the Ancoats site was chosen to site the Drawn Study on. It is in closest proximity to the city centre which, combined with the scale of the surrounding buildings, means that it has the highest degree of urbanity; therefore the density of development can be higher than would be appropriate to the other sites, and thus more efficient use of the land can be made. The site is currently used as a car park, and therefore its development replaces a non-sustainable use. Whilst all of the sites are brownfield, either in whole or in part, the Ancoats site has a very low ecological value as it is completely devoid of any vegetation.

Existing buildings along Dale Street define the southwest boundary of the site, toward the city centre; at this edge the site is predominantly vacant and therefore its boundaries are clearly discernible. This continues around the edges that are bounded to the northwest by China Lane and Port Street; these edges have the strongest contextual grain, where the fabric of the city abuts vacant land. Great Ancoats Street clearly suggested the northeastern edge; along which the site is also predominantly vacant. The southeastern boundary of the site, Store Street, was established in response to the topography of the site. It lies in a small valley, and marks a point at which the character of the surrounding context changes, becoming more inner urban rather than central.

Historical Analysis

Research confirmed what the few remnants suggested; the site used to have a fabric predominated by warehouses and spurs of the canal. These provided a hub for the movement of cotton from the mills on the Pennines to the former goods railway station on the site, and from there across the country.

Research was conducted to establish the site's history, studying its changing patterns of use over time and its role in the overall historical structure of the city. The analysis began from 1848, which was the earliest map of the city that could be located. Plans of the site from periodic intervals were studied, a selected range of which is included on sheet 1 of the Drawn Study.

The clearest existing indications of the role of the site are the canal, the architecture of the few buildings on the site, and those that surround it toward the city centre. These are predominantly warehouses, which were served by the Rochdale and the Manchester and Ashton canals that meet at the centre of the site, and which lead out from the city toward the cotton mills on the Lancashire side of the Pennies. The plan of 1891 clearly shows the wharves and warehouses that once covered the site; at this time buildings and water were the predominant elements within the urban fabric of the site. Also shown are the railway sidings that led past Piccadilly, formerly London Road, Station into the goods station that once stood on the southeast edge of the site, by Store Street. It can be speculated that the site was a distribution point for moving the produce of the mills onto the railways for transportation across the country, and therefore it played a role in the commercial evolution of the city. At this time the site also contained terraced housing.

With the exception of some minor alterations to the northeast corner, this fabric was retained until at least 1956, and survived the bombing of Manchester during the war. By 1980 the grain of the site had radically altered. The historical legacy of the site was all but erased; the only remaining remnants were the canal, a small number of existing buildings, and a fragment of wall with an arched gateway, which probably encircled part of the site to secure the wares inside. This gateway, on Dale Street, lies at the end of Lena Street, which provides the most direct route to the city centre from the site. The two canals that exist are all that remains of what appears to have been an almost Venetian-like quality of that part of the city.

Conceptual Structure of the Grain

The structure of the urban grain was created as a palimpsest of layers, which reflect the historical antecedence of the site, its urban and architectural context, and movement routes. A network of urban squares was proposed, which are linked by pedestrian routes. In response to the scale of the buildings that surround the site, the vertical scale of the masterplan falls from west to east. Whilst cars would be able to permeate through most of the site, pedestrian and cycle routes are predominant, and the dwellings were proposed as car free.

The response to the historical, urban and architectural context of the site in the design of the plan was threefold. Firstly the existing block structure of the surrounding urban fabric was extended over the master plan at the edges that face the city centre, in order to stitch the new and existing together. The most significant access into the site orientates itself to this grain, and originates within the existing part of it; this axis flows through the existing arch in a fragment of the original wall surrounding the edge of the site. Another edge was created against the canal, which is one of the only other historical elements remaining on the site; where the geometry of the historical grid and the canal meet, the principal urban square was created; a pivot about which the geometry hinges.

The second response to the context of the site would be the excavation of parts of the canal that have previously been filled in; the intention, rather than pure historicism, would be to extend the network of routes that cross the site as canal towpaths for pedestrians and cyclists. In the three dimensional morphology of the site, the vertical mass of the surrounding fabric was carried onto the masterplan as the third contextual response, ensuring that the density at the edges of the site next to the city centre was directly comparable to the most historically and contextually significant existing fabric. Therefore it was considered that the design fulfilled the benchmark of the Contextual Significance of the Site.

A palimpsest of layers is created that in combination generate the structure of the urban grain. The desirable east to west orientation that maximises the benefit of passive solar gain was overlaid with the influence of the adjacent block structure of the city identified above. Also, the historical antecedence of the site as a network of warehouses linked by canals was re-established and increased within the plan as a layer of circulation routes.

Finally the generic Mercator grid was overlaid, which related back to the desirable east to west orientation. These layers emerge and recede so that different ones predominate in various areas across the site.

There are several principal routes within the grain. The axis that was established by the arched remnant of the site's historical antecedence, which leads to the principal public square, would be the main access into the grain from the city centre. From that square the canal towpaths lead outward toward the other areas of the plan. Raising the significance of the canals that bisect the site was a response to the role that they once had in the urban grain of the site. These pedestrian and cycle routes are in addition to the existing network of roads, which remain unchanged, and the new routes throughout the site. Using the canals as primary pedestrian routes through the plan also provided a way in which to create a relative sense of tranquillity within an intense, urban environment, and therefore attempt to achieve a psychological detachment upon the approach to a dwelling. Finally a north to south axis established by the Mercator grid linked a series of urban squares, including the principal public space, throughout the masterplan. This axis would be terminated to the north by the point of inflection in one of the urban blocks where it mediates between two geometries, and to the south by a building; the axis extended beyond these points as a design line to locate other squares within the plan. The principal urban square was located at the centre of this axis, where it crossed that of the main route into the site from the city centre. A network of urban squares was therefore proposed throughout the site, which would be linked together by pedestrian routes.

The vertical scale of the urban grain falls across the masterplan in response to the surrounding fabric of the city, as established above. At the southwest edge, the buildings within the site would be, like those around them, typically five and six storeys in height. This scale falls away gradually, although was increased again at significant points, such as the principal urban square. At the northeast edge of the site, buildings were proposed at three and four storeys.

At the scale of the urban district, the design proposed a three dimensional masterplan for the site. This would be a mixed function proposal, incorporating retail, commercial, and light industrial functions in addition to those required by those dwelling within the site, such as a kindergarten and medical centre. As the strategy for the wider site would include existing buildings, two of which have been recently redeveloped, these would become a part of the plan as they reach the end of their life. In this sense the overall strategy was seen as a plan for the evolution of the area over the longer term. The proposed land use within the site was broken down into its component parts in the following table.

	Area (Hectares)
Total site area	11.68
Strategic open space	1.16
Net housing area	6.31
Dwelling space (All floors)	66.2
Commercial space (All floors)	51.4
Industrial space	11.0

Land use within the Drawn Study by area.

It is considered that an 'urban village' requires at least 15 percent of the total floor space to be non-housing to create sufficient diversity. The Drawn Study evidently more than achieved this; however, given the location of a site in very close proximity to a city centre, it was considered that the increased proportion of non-domestic functions would be justified.

In terms of phasing, the area surrounding the principal public space at the southwestern corner of the site was perceived as the progenitor for the wider plan. This area is currently vacant and therefore development is viable within the near future. Furthermore, it would provide a link between the existing fabric of the city and the overall site, weaving the new into the existing; to commence development elsewhere would create a void between these two.

The primary pedestrian and cycle routes that link the parts of the site together have been identified above. The car would be able to permeate most areas of the plan, but not via all of the routes that structure it; some, in addition to the primary ones identified above, would be exclusively for movement by foot and by bicycle. Perhaps contentiously, the car would have few areas in which to park within the site. Car free developments have both contemporary and historical precedents, including the New Town and sustainable housing project in Edinburgh, the latter by Hackland and Dore. It was considered that for a project in which a significant emphasis has been placed upon ecological sustainability, and one in such proximity to the facilities of a metropolitan city centre, local transport modes of tram and bus, and regional and national railways, a car-free approach to the dwellings was justifiable. A small number of covered spaces were included, for the houses as opposed to the flats, and for the vehement opposer of sustainable transport or those for whom the car is an absolute necessity. In the desirable event that these spaces are not required, the buildings would be used as small workshops.

Density

Four three-dimensional scenarios were developed, which varied the dwelling types and vertical scale of the masterplan. This tested the robustness of the Drawn Study, in terms of its ability to evolve whilst retaining its conceptual structure, and validated the appropriateness of the benchmark value.

Four scenarios of different configurations of the urban form within the masterplan were studied, varying the proportion of flats and houses, and varying the heights of buildings. This served to evaluate the impact that each had on the net residential density; a process that also tested the robustness of the urban grain, to establish if it could respond to different mixtures of dwelling types, density and vertical scale. It also demonstrated that creative design could lead the benchmark, and not vice versa. The outcome was a series of density benchmarks, depending upon the mix and vertical scale of the urban grain proposed.

The first scenario was based upon the largest number of houses that could be incorporated onto the site, whilst still retaining an urban scale to the grain. This represented an attempt to provide a more even balance between the number of houses and the number of flats within the masterplan. The second scenario also incorporated houses, but to a lesser extent. They were located in areas where the vertical scale of the grain had dropped, reflecting a decrease in the height of the buildings that surround the site. Variations of the mix of dwelling types tested the ability of the plan to respond to potential different market scenarios, such as 100 percent flats, maximum houses, or a mixture, and therefore tested its robustness. The third scenario had a similar scale of grain to that of the second, but did not include any houses, only flats, as a dwelling type. The vertical scale of the grain was then increased for the final scenario, but the plan form kept the same. Mixed functions were included in equal numbers in all of the scenarios. On sheet 2 of the 3 in this Drawn Study, the four scenarios are shown as axonometric drawings, to represent the differences in scale between each. The number of dwellings, designed population and consequent net residential density of each is shown in the following table.

Scenario	Houses	Flats	Inhabitants	Density (p.ha^{-1})
1	148	696	1,984	**314**
2	37	1,144	2,436	**386**
3	0	1,264	2,528	**401**
4	0	1,583	3,166	**502**

Four density scenarios for Drawn Study Six

The second scenario was chosen to be developed further, which gives a quantitative density benchmark of 386 p.ha^{-1}. It was selected for two reasons. Firstly, it has a benchmark closest to that of the 'urban house in paradise', and therefore demonstrates the nature and scale of urban form required to achieve the benchmark. Secondly, it includes both houses and flats. It was considered that designing a house that would achieve the benchmarks of the 'urban house in paradise', as opposed to a flat, would present more challenges, and therefore constitute a more thorough and robust validation of the benchmark values. Whilst it might be construed that the fourth scenario is more appropriate to a site with close proximity to a city centre, as it has the greatest vertical scale, it was considered that the decrease in height of the surrounding buildings from west to east around the site is most reflected in the second and third scenarios.

Diversity and Ecological Significance

Almost half of the total floor area proposed in the Study would be allocated for non-dwelling functions. The programmatic diversity of the first phase was calculated as 56 functions per hectare. The challenge of sustaining this level of diversity across the site was identified.

62,000 m^2 of floor space was proposed for functions other than dwelling within the masterplan. Of this, 51,00 m^2 was proposed as commercial, which would include retail, leisure and office space. Around the western side of the site, and encircling the urban squares throughout it, the ground floors of the buildings would house commercial functions with dwellings over. Facilities such as a kindergarten and medical centre were also proposed. The sustainability of these functions would not be solely dependent upon the population of the site, even for those predicated towards serving the dwellings due to the number of housing projects that are being developed in the immediate vicinity of the site. Other commercial functions within the site could include cafés and bars, restaurants and a gymnasium. The light industrial spaces included in the plan would be located toward the southeast edge of the site, reflecting the current land use in these areas.

The area of the site envisaged as a first phase, including the main access to the site and principal urban space, was analysed in terms of the proposed number of functions that it could accommodate. With a blend of the functions described, the benchmark was estimated at 56 functions per hectare. A challenge would be to sustain this level of diversity across the site. However, the diversity benchmark is based upon the capacity of the design to accommodate these functions; it cannot assess the commercial viability of achieving them.

For the second of the four scenarios that was developed for the masterplan, the total floor area of the dwellings has been calculated as 65,529 m^{-2}. Within the plan 1.45 ha of land has been proposed as green space, as either strategic open space, semi-private gardens around apartment blocks, or as private gardens. Therefore the proportion of green space to the floor area of the dwellings can be calculated as 22 percent. This was slightly below the benchmark proposed by the 'urban house in paradise'. If, however, the open space provided by the canal were included within this value, the proportion of soft landscape would be 29 percent of the total floor area of the dwellings. Whilst it was not proposed that the existing canals be converted to green space, if the new water spaces were green open space instead, the benchmark of 25 percent would be achieved.

The site is 100 percent brownfield. Although it may have been vacant for a number of years, there was no evidence of flora on the site, and therefore it was not thought to provide any habitat. The assessment of the benchmark for the criterion of Ecological Significance of the Site requires identification of any water on the site; however this is restricted to ponds, streams and rivers, and does not include canals. As the plan did not propose any alteration to the existing canals, only expanding and improving their condition, it was not thought any detrimental impact on species living within them would be made.

The performance of the Drawn Study in terms of the criteria of the 'urban house in paradise' can be seen in the table overleaf.

Criteria		Benchmarks
		Ancoats: Urban District
CO_2 emissions: Inhabitation: kgCO2.m-2.a-1		Assessed in Drawn Study 8
CO_2 emissions: On Site Construction Processes: kgCO2.m-2		Assessed in Drawn Study 8
Carbon intensity: kg.kWh-1		Assessed in Drawn Study 8
Construction period: weeks per dwelling		Assessed in Drawn Study 7
Contextual significance of site: Qualitative		Yes
Deconstruction and demolition: Recycling materials: Percent		Assessed in Drawn Study 8
Design life span: Years		Assessed in Drawn Study 7
Density:	quantitative: p.ha-1	386
	qualitative	Yes
Diveristy: programmes.ha-1		56
Domestic waste:	refuse: kg.p-1.wk-1	Assessed in Drawn Study 7
	recycled: kg.p-1.wk-1	Assessed in Drawn Study 7
Ecological significance of the site: Percent and qualitative		100, Yes and Yes
Ecological weight: embodied energy: kWh.m-2		Assessed in Drawn Study 8
Ecological weight: CO_2 emissions: kgCO2.m-2		Assessed in Drawn Study 8
Energy consumption: construction: kWh.m-2		Assessed in Drawn Study 8
Energy consumption: inhabitation: kWh.m-2.a-1		Assessed in Drawn Study 8
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study 8
Green space: Percent		22
Lifecycle cost:	Construction: £.m-2.a-1	Assessed in Drawn Study 7
	Energy: £.m-2.a-1	Assessed in Drawn Study 7
	Water: £.p-1.a-1	Assessed in Drawn Study 7
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study 8
Other ecological impacts of materials: Qualitative, g.kWh-1		Assessed in Drawn Study 8
Other greenhouse gas emissions: g.kg-1		Assessed in Drawn Study 8
Pollution: energy consumption inhabitation: g.kWh-1		Assessed in Drawn Study 8
Procurement strategy: Qualitative		Performance spec
Quality of internal environment:	indoor pollution: Qualitative	Assessed in Drawn Study 7
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 7
	ventilation: ac.h-1	Assessed in Drawn Study 7
	airtightness: ac.h-1 at 50 Pa	Assessed in Drawn Study 7
Recycling construction waste: Percent		Not Assessed
Adaptability: Internal loadbearing walls: Internal walls		Assessed in Drawn Study 7
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	Not Applicable
	3 persons: m2.p-1	Not Applicable
	4 persons: m2.p-1	Not Applicable
	5 persons: m2.p-1	Assessed in Drawn Study 7
	6 persons: m2.p-1	Assessed in Drawn Study 7
	7 persons: m2.p-1	Not Applicable
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
	4 persons: m3.p-1	Not Applicable
	5 persons: m3.p-1	Assessed in Drawn Study 7
	6 persons: m3.p-1	Assessed in Drawn Study 7
	7 persons: m3.p-1	Not Applicable
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance:	Roof: W.m-2.K-1	Assessed in Drawn Study 7
	Exposed walls: W.m-2.K-1	Assessed in Drawn Study 7
	Ground and exposed floors: W.m-2.K-1	Assessed in Drawn Study 7
	Windows and rooflights: W.m-2.K-1	Assessed in Drawn Study 7
	Opaque outer doors: W.m-2.K-1	Assessed in Drawn Study 7
Use of recycled materials: Percent		Assessed in Drawn Study 8
Use of renewable raw materials: Percent		Assessed in Drawn Study 8
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Assessed in Drawn Study 8
Water consumption: inhabitation:	potable: l.p-1.d-1	Assessed in Drawn Study 7
	rain and grey: l.p-1.d-1	Assessed in Drawn Study 7
	total: l.p-1.d-1	Assessed in Drawn Study 7

Benchmark performance of Drawn Study 6

Drawn Study Six

Site

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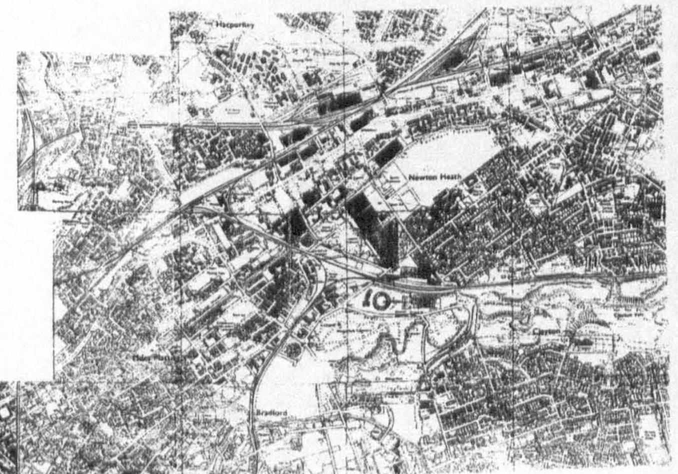
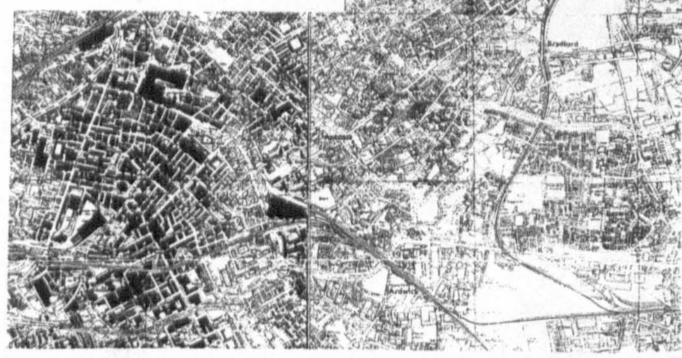
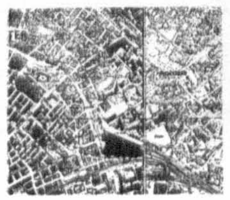
Sites initially considered for the Drawn Study

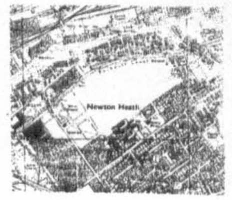




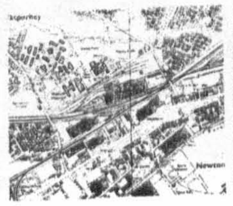


Site 1

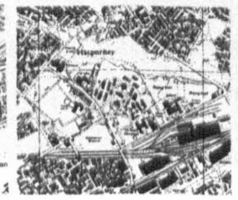
Site 2



Site 3

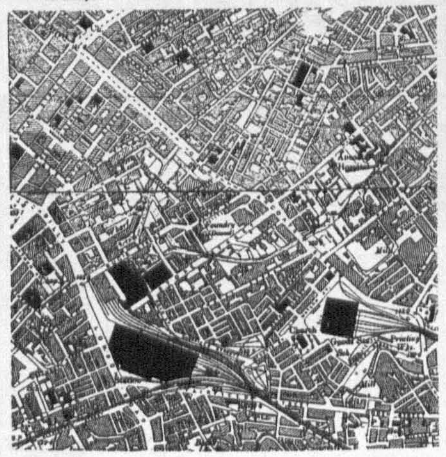


Site 4

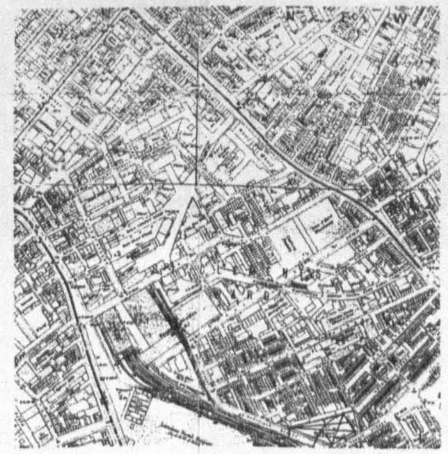


Site 5

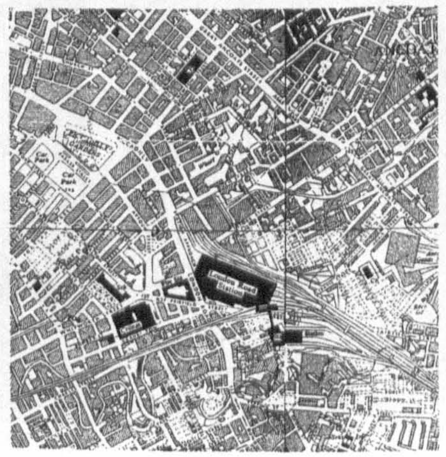
Historical analysis



Site in 1895



Site in 1915



Site in 1956

Site in 1980

Ancoats: Scale of the Urban District and Site

Historical Analysis

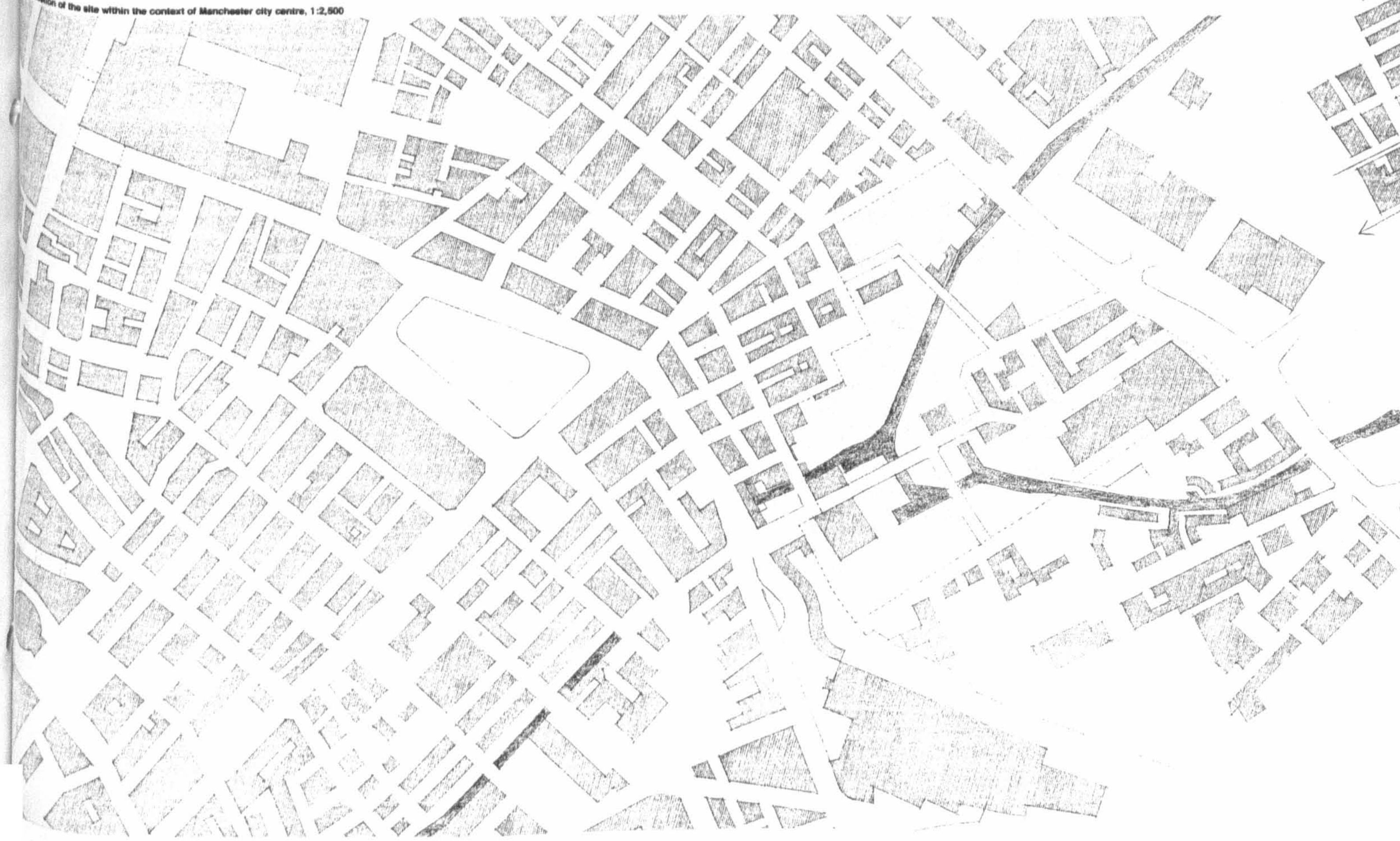
Research confirmed what the few remnants suggested; the site used to have a fabric predominated by warehouses and spurs of the canal. These provided a hub for the movement of cotton from the mills on the Pennines to the former goods railway station on the site, and from there across the country.

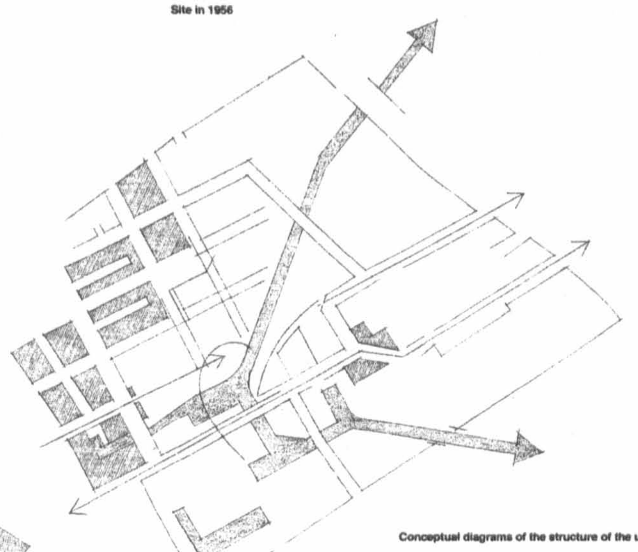
Research was conducted to establish the site's history, studying its changing patterns of use over time and its role in the overall historical structure of the city. The analysis began from 1848, which was the earliest map of the city that could be located. Plans of the site from periodic intervals were studied.

The clearest existing indications of the role of the site are the canal, the architecture of the few buildings on the site, and those that surround it toward the city centre. These are predominantly warehouses, which were served by the Rochdale and the Manchester and Ashton canals that meet at the centre of the site, and which lead out from the city toward the cotton mills on the Lancashire side of the Pennies. The plan of 1891 clearly shows the wharves and warehouses that once covered the site; at this time buildings and water were the predominant elements within the urban fabric of the site. Also shown are the railway sidings that led past Piccadilly, formerly London Road, Station into the goods station that once stood on the southeast edge of the site, by Store Street. It can be speculated that the site was a distribution point for moving the produce of the mills onto the railways for transportation across the country, and therefore it played a role in the commercial evolution of the city. At this time the site also contained terraced housing

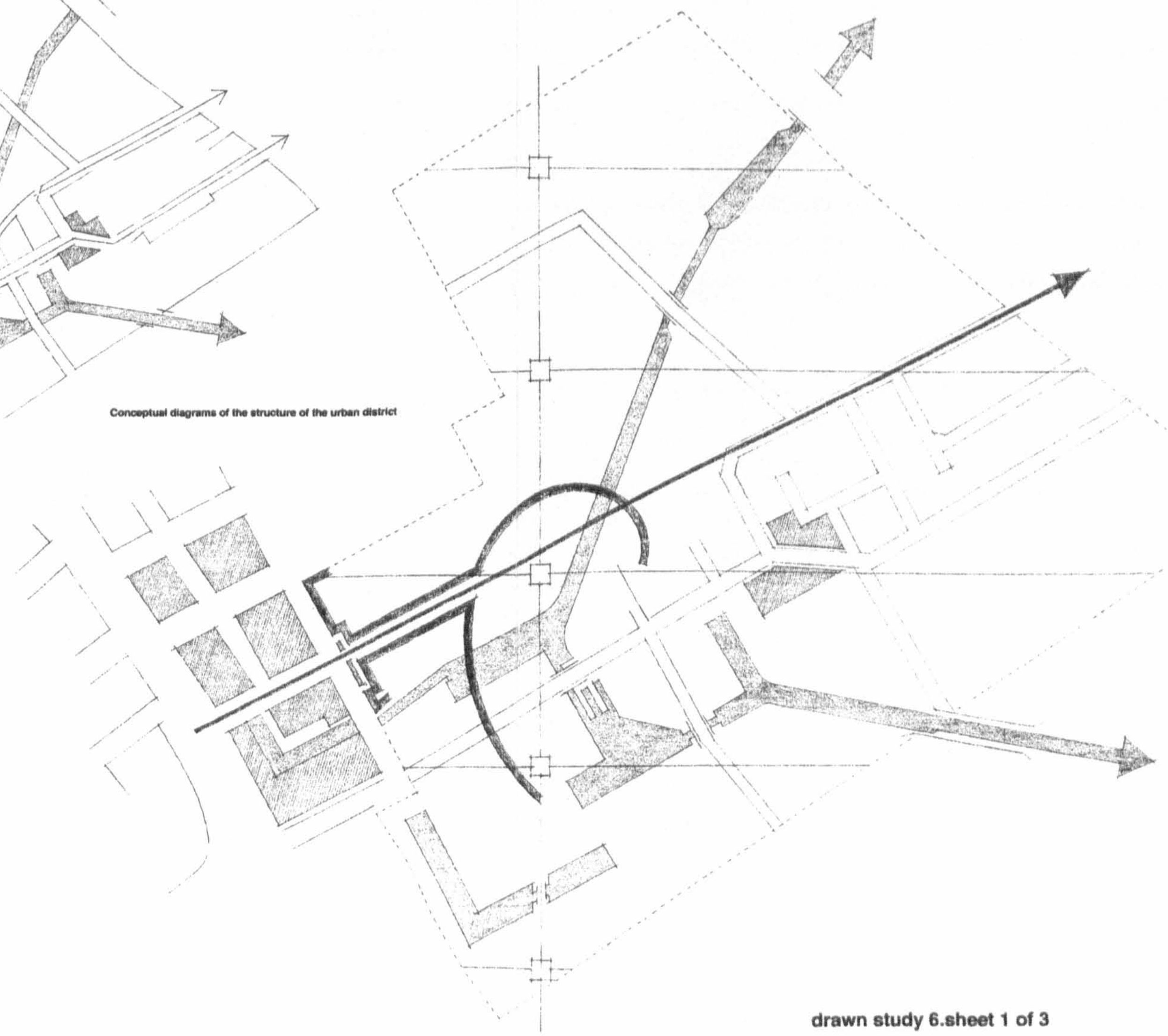
With the exception of some minor alterations to the northeast corner, this fabric was retained until at least 1956, and survived the bombing of Manchester during the war. By 1980 the grain of the site had radically altered. The historical legacy of the site was all but erased; the only remaining remnants are the canal, a small number of existing buildings, and a fragment of wall with an arched gateway, which probably encircled part of the site to secure the wares inside. This gateway, on Dale Street, lies at the end of Lena Street, which provides the most direct route to the city centre from the site. The two canals that exist are all that remains of what appears to have been an almost Venetian-like quality of that part of the city.

Location of the site within the context of Manchester city centre, 1:2,500





Conceptual diagrams of the structure of the urban district



Drawn Study Six

The Drawn Study provides the urban context into which to locate a dwelling, which will be designed in the subsequent two Studies. Collectively these last Studies attempt to evaluate the criteria, benchmarks and assessment methodology of the 'urban house in paradise', to establish if it is a realisable concept.

Whereas Drawn Studies 1 to 5 were exploratory, the basic brief for the final three was to test and validate the criteria, benchmarks and assessment tool that collectively define and measure the 'urban house in paradise'. In addition to this, it was considered that they should respond to other agendas that need to be addressed in developing urban housing, such as demographic change and the Urban Task Force report, so that the research methodology is not abstract to issues of contemporary practice.

There were three scales of study for the Ancoats project. The urban scale is manifested into a two and three-dimensional block masterplan, studying the grain, morphology and dwelling types required to achieve the relevant benchmarks set by the thesis. This established the context into which an individual dwelling could be set, the design of which constituted the second scale of study. Thirdly, the construction technology of that dwelling was evaluated. Collectively the scope of these three Studies was to be sufficient to evaluate the performance against all of the benchmarks of the 'urban house in paradise'. As the benchmarks have been derived from a multitude of sources, these Drawn Studies aimed to establish if they could be achieved in one project, or if any are mutually exclusive to the others.

Because the primary aim of the study was to provide material against which to assess and validate the 'urban house in paradise' benchmarks and assessment tool, the focus of the work was on the latter two scales of study, which the tool is predicated toward. However, the urban scale was important on two levels: firstly in providing the context in which to create the dwelling, and secondly in validating the benchmarks of the tool that apply to the urban scale, such as density, green space and programmatic diversity.

Conceptual Structure of the Grain

The structure of the urban grain was created as a palimpsest of layers, which reflect the historical antecedence of the site, its urban and architectural context, and movement routes. A network of urban squares was proposed, which are linked by pedestrian routes. In response to the buildings that surround the site, the vertical scale of the masterplan falls from west to east. Whilst cars would be able to permeate through most of the site, pedestrian and cycle routes are predominant, and the dwellings were proposed as car free.

The response to the historical, urban and architectural context of the site in the design of the plan was threefold. Firstly the existing block structure of the surrounding urban fabric was extended over the master plan at the edges that face the city centre, in order to stitch the new and existing together. The most significant access into the site orientates itself to this grain, and originates within the existing part of it; this axis flows through the existing arch in a fragment of the original wall surrounding the edge of the site. Another edge was created against the canal, which is one of the only other historical elements remaining on the site, where the geometry of the historical grid and the canal meet, the principal urban square was created; a pivot about which the geometry hinges.

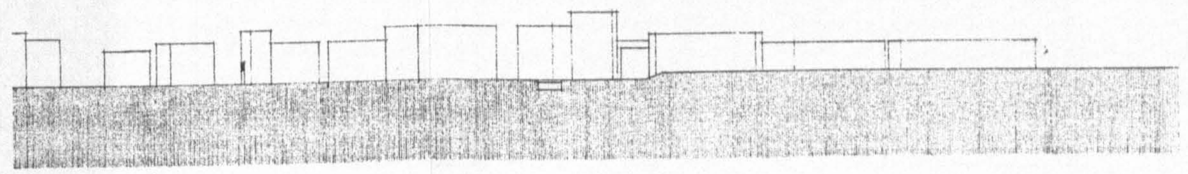
The second response to the context of the site would be the excavation of parts of the canal that have previously been filled in; the intention, rather than pure historicism, was to extend the network of routes that cross the site as canal towpaths for pedestrians and cyclists. In the three dimensional morphology of the site, the vertical mass of the surrounding fabric was carried onto the masterplan as the third contextual response, ensuring that the density at the edges of the site next to the city centre was directly comparable to the most historically and contextually significant existing fabric. Therefore it was considered that the design does fulfil the benchmark of the Contextual Significance of the Site.

A palimpsest of layers was created that, in combination, generate the structure of the urban grain. The desirable east to west orientation that maximises the benefit of passive solar gain was overlaid with the influence of the adjacent block structure of the city identified above. Also, the historical antecedence of the site as a network of warehouses linked by canals was re-established and increased within the plan as a layer of circulation routes. Finally the generic Mercator grid was overlaid, which relates back to the desirable east to west orientation. These layers emerge and recede so that different ones predominate in various areas across the site.

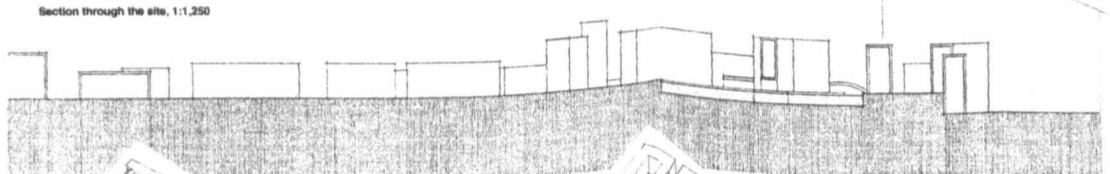
There are several principal routes within the grain. The axis that was established by the arched remnant of the site's historical antecedence, which leads to the principal public square, was the main access into the grain from the city centre. From that square the canal towpaths lead outward toward the other areas of the plan. Raising the significance of the canals that bisect the site was a response to the role that they once had in the urban grain of the site. These pedestrian and cycle routes are in addition to the existing network of roads, which remain unchanged, and the new routes throughout the site. Using the canals as the primary pedestrian routes through the plan also provided a way in which to create a relative sense of tranquillity within an intense, urban environment, and therefore attempt to achieve a psychological detachment upon the approach to a dwelling. Finally a north to south axis established by the Mercator grid would link a series of urban squares, including the principal public space, throughout the masterplan. This axis would be terminated to the north by the point of inflection in one of the urban blocks, where it mediates between two geometries, and to the south by a building; the axis extended beyond these points as a design line to locate other squares within the plan. The principal urban square was located at the centre of this axis, where it crosses that of the main route into the site from the city centre. A network of urban squares was therefore proposed throughout the site, which would be linked together by pedestrian routes.

Masterplan of the Ancoats site, 1:1,250

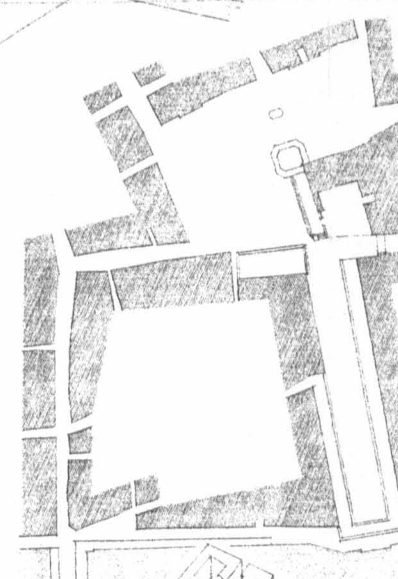
Plan Key
A. Residential over commercial and retail space
B. Principal public open space
C. Green open space
D. Residential
E. Commercial
F. Light industrial quarter



Section through the site, 1:1,250



Section through the site, 1:1,250



Comparative urban space
Piazza della Signoria, Florence, 1:1,250

Density

Four three-dimensional scenarios were developed, which varied the dwelling types and vertical scale of the masterplan. This tested the robustness of the Drawn Study, in terms of its ability to evolve whilst retaining its conceptual structure, and validated the appropriateness of the benchmark value.

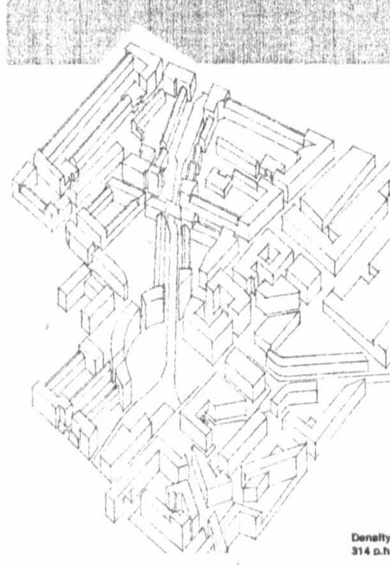
Four scenarios of different configurations of the urban form within the masterplan were studied, varying the proportion of flats and houses, and varying the heights of buildings. This served to evaluate the impact that each had upon the net residential density; a process that also tested the robustness of the urban grain, to establish if it could respond to different mixtures of dwelling types, density and vertical scale. It also demonstrated that creative design could lead the benchmark, and not vice versa. The outcome was a series of density benchmarks, depending upon the mix and vertical scale of the urban grain proposed.

The first scenario was based upon the largest number of houses that could be incorporated onto the site, whilst still retaining an urban scale to the grain. This represented an attempt to provide a more even balance between the number of houses and the number of flats within the masterplan. The second scenario also incorporated houses, but to a lesser extent. They were located in areas where the vertical scale of the grain had dropped, reflecting a decrease in the height of the buildings that surround the site. Variations of the mix of dwelling types tested the ability of the plan to respond to potential different market scenarios, such as 100 percent flats, maximum houses, or a mixture, and therefore tested its robustness. The third scenario had a similar scale of grain to that of the second, but did not include any houses, only flats, as a dwelling type. The vertical scale of the grain was then increased for the final scenario, but the plan form kept the same. Mixed functions were included in equal numbers in all of the scenarios. The four scenarios are shown as axonometric drawings, to represent the differences in scale between each. The number of dwellings, designed population and consequent net residential density of each is shown in the following table.

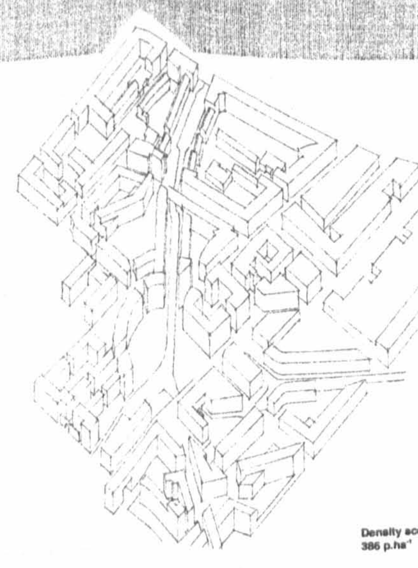
Scenario	Houses	Flats	Inhabitants	Density ($p.ha^{-1}$)
1	148	696	1,984	314
2	37	1,144	2,436	386
3	0	1,264	2,528	401
4	0	1,583	3,166	502

Four density scenarios for Drawn Study Six

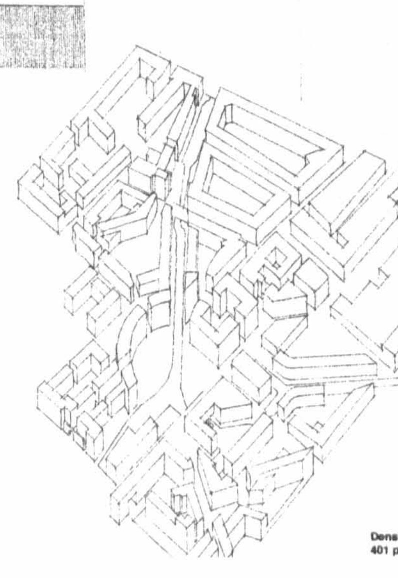
The second scenario was chosen to be developed further, which gives a quantitative density benchmark of 386 $p.ha^{-1}$. It was selected for two reasons. Firstly, it has a benchmark closest to that of the 'urban house in paradise', and therefore demonstrates the nature and scale of urban form required to achieve the benchmark. Secondly, it includes both houses and flats. It was considered that designing a house that would achieve the benchmarks of the 'urban house in paradise', as opposed to a flat, would present more challenges, and therefore constitute a more thorough and robust validation of the benchmark values. Whilst it might be construed that the fourth scenario is more appropriate to a site with close proximity to a city centre, as it has the greatest vertical scale, it was considered that the decrease in height of the surrounding buildings from west to east around the site is most reflected in the second and third scenarios.



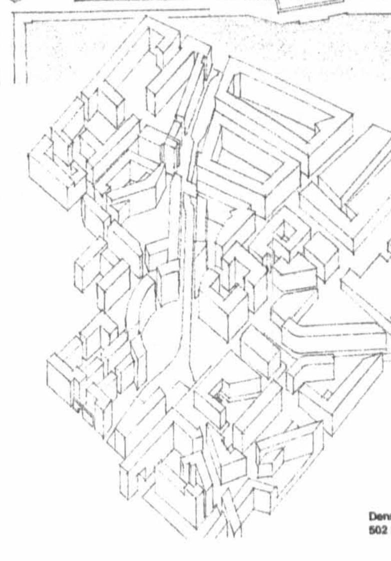
Density scenario 1
314 $p.ha^{-1}$



Density scenario 2
386 $p.ha^{-1}$



Density scenario 3
401 $p.ha^{-1}$



Density scenario 4
502 $p.ha^{-1}$

Drawn Study Six

Morphology

At the scale of the urban district, the design proposed a three dimensional, mixed function masterplan for the site. The vertical scale of the urban grain falls across the masterplan in response to the surrounding fabric of the city, although was increased at strategic points to reflect significant spaces.

At the scale of the urban district, the design proposed a three dimensional masterplan for the site. This was a mixed function proposal, incorporating retail, commercial, and light industrial functions in addition to those required by those dwellings within the site, such as a kindergarten and medical centre. As the strategy for the wider site would include existing buildings, two of which have been recently redeveloped, these would become a part of the plan as they reach the end of their life. In this sense the overall strategy was seen as a plan for the evolution of the area over the longer term. In terms of phasing, the area surrounding the principal public space at the southwestern corner of the site was perceived as the progenitor for the wider plan. This area is currently vacant and therefore development would be viable within the near future. Furthermore, it would provide a link between the existing fabric of the city and the overall site, weaving the new into the existing; to commence development elsewhere would create a void between these two.

The vertical scale of the urban grain falls across the masterplan in response to the surrounding fabric of the city. At the southwest edge, the buildings within the site would be, like those around them, typically five and six storeys in height. This scale falls away gradually, although was increased again at significant points such as the principal urban square. At the northeast edge of the site, buildings were proposed at three and four storeys.

The primary pedestrian and cycle routes that link the parts of the site together have been identified. The car would be able to permeate most areas of the plan, but not via all of the routes that structure it; some, in addition to the primary ones identified above, would be exclusively for movement by foot and by bicycle. Perhaps contentiously, the car would have few areas in which to park within the site. Car free developments have both contemporary and historical precedents, including the New Town and sustainable housing project in Edinburgh, the latter by Hackland and Dore. It was considered that for a project in which a significant emphasis has been placed upon ecological sustainability, and one in such proximity to the facilities of a metropolitan city centre, local transport modes of tram and bus, and regional and national railways, a car-free approach to the dwellings was justifiable. A small number of covered spaces would be included, for the houses as opposed to the flats, and for the vehement opposer of sustainable transport, or those for whom the car is an absolute necessity. In the desirable event that these spaces are not required, they could be used as small workshops.

Diversity

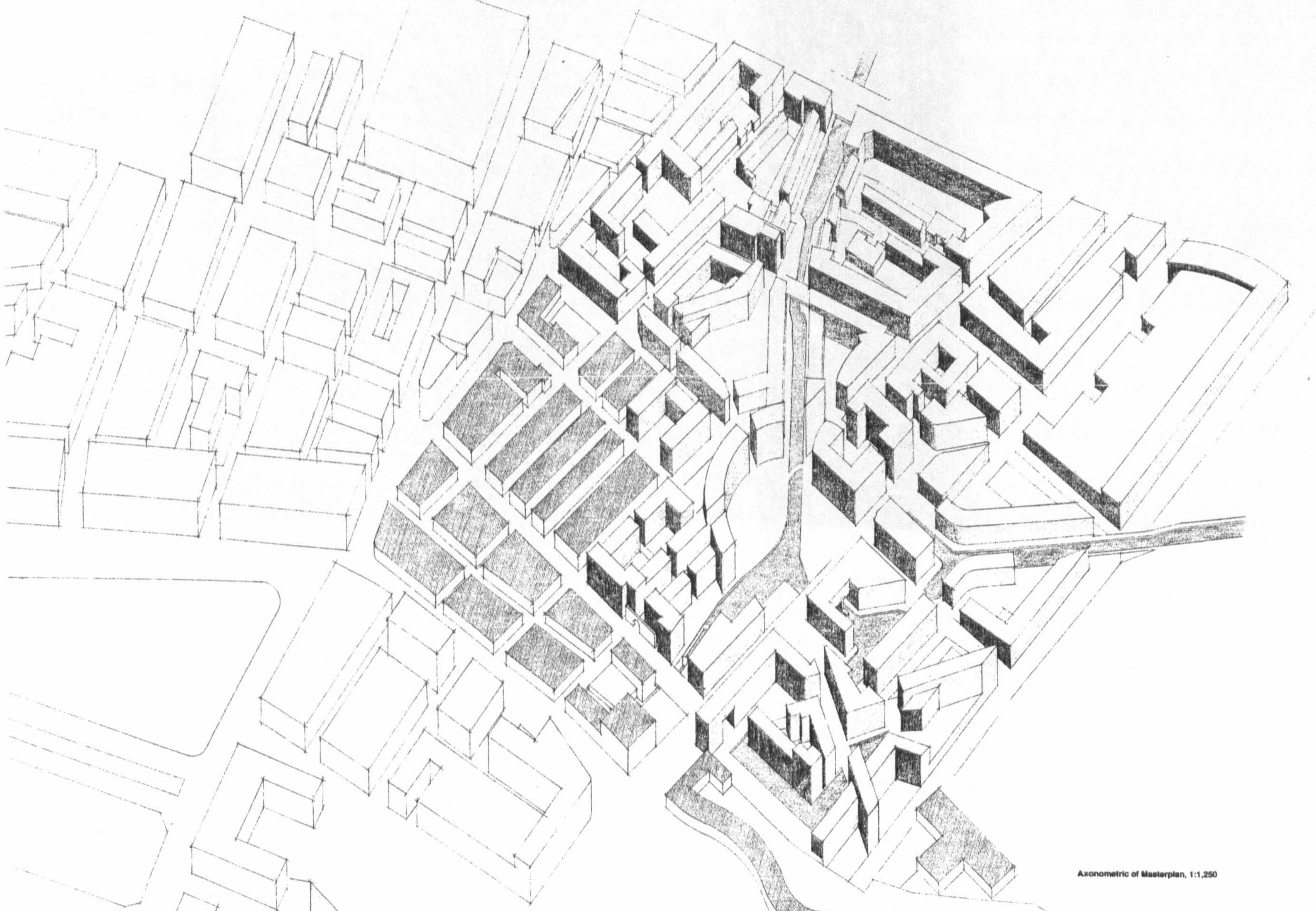
Almost half of the total floor area proposed in the Study would be allocated for non-dwelling functions. The programmatic diversity of the first phase was calculated as 56 functions per hectare. The challenge of sustaining this level of diversity across the site was identified.

The proposed land use within the site was broken down into its component parts in the following table

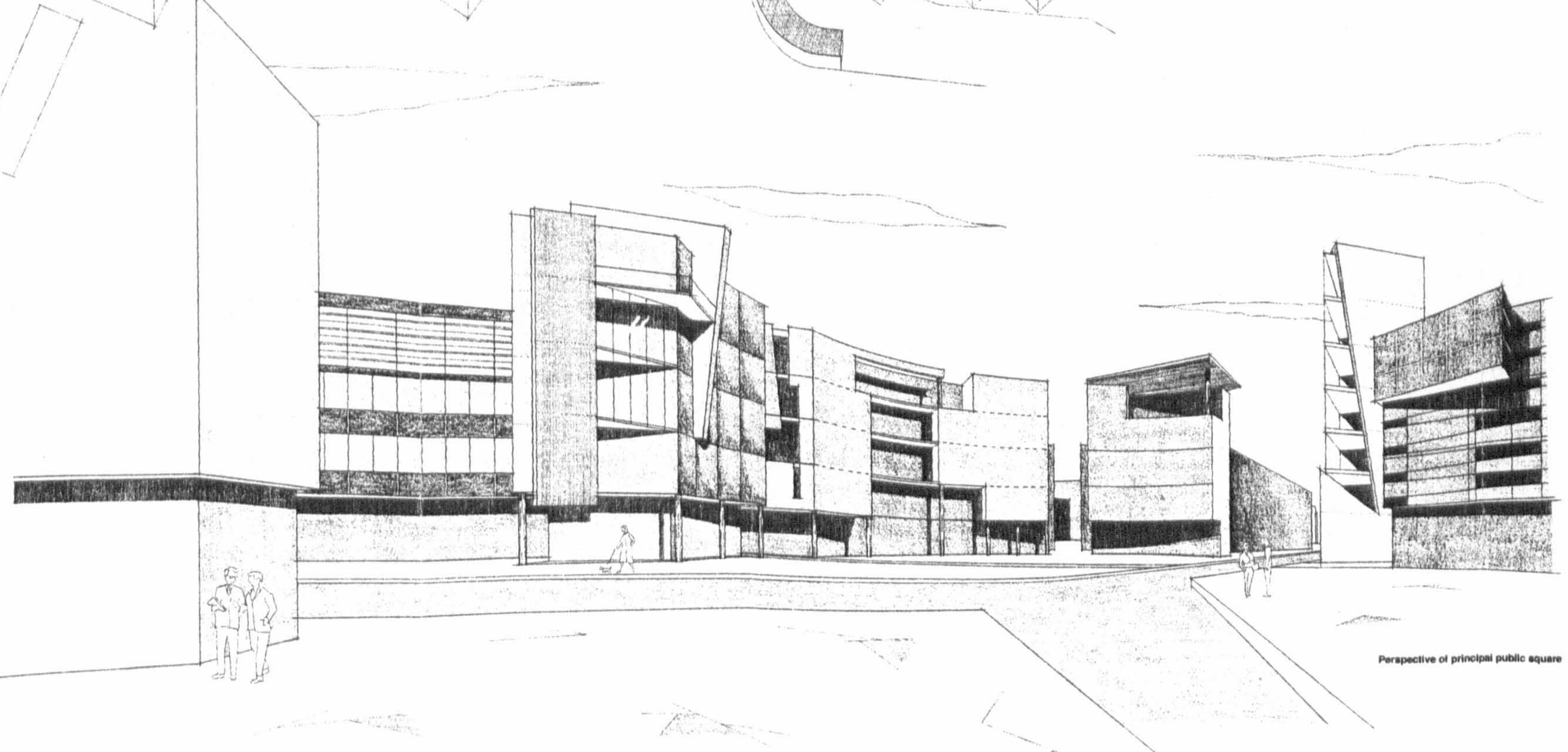
	Area (Hectares)
Total site area	11.68
Strategic open space	1.16
Net housing area	6.31
Dwelling space (All floors)	65.5
Commercial space (All floors)	51.4
Industrial space	11.0

Land use within the Drawn Study by area

It is considered that an 'urban village' requires at least 15 percent of the total floor space to be non-housing to create sufficient diversity. The Drawn Study evidently more than achieved this; however, given the location of a site in very close proximity to a city centre, it was considered that the increased proportion of non-domestic functions would be justified. 62,000 m² of floor space was proposed for functions other than dwelling within the masterplan. Of this, 51,00 m² was proposed as commercial, which would include retail, leisure and office space. Around the western side of the site, and encircling the urban squares throughout it, the ground floors of buildings would house commercial functions with dwellings over. Facilities such as a kindergarten and medical centre were also proposed. The sustainability of these functions would not be solely dependent upon the population of the site, even for those predicated towards serving the dwellings, due to the number of housing projects that are being developed in the immediate vicinity of the site. Other commercial functions within the site would include cafés and bars, restaurants and a gymnasium. The light industrial spaces included in the plan would be located toward the southeast edge of the site, reflecting the current land use in these areas.



Axonometric of Masterplan, 1:1,250



Perspective of principal public square

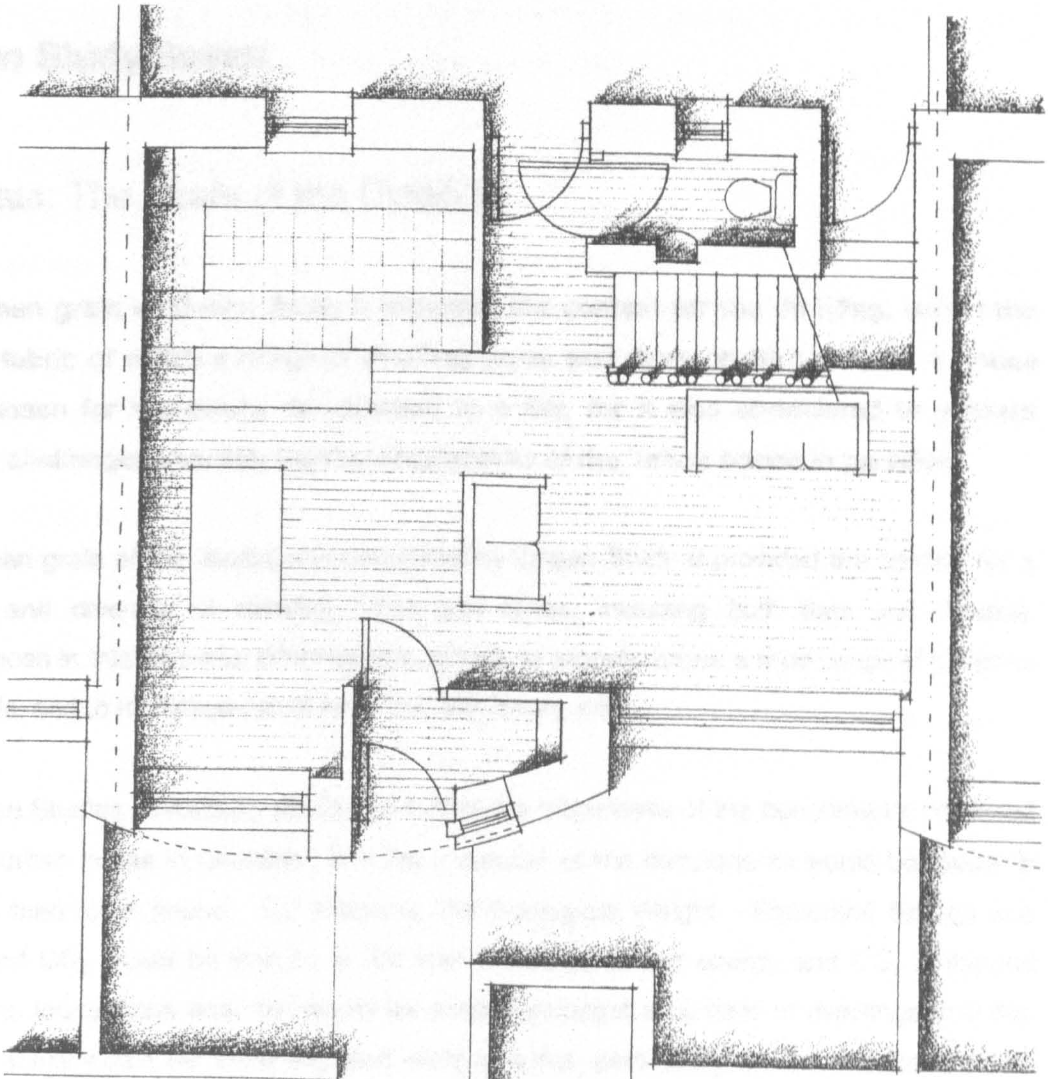
The area of the site envisaged as a first phase, including the main access to the site and principal urban space, was analysed in terms of the proposed number of functions that it could accommodate. With a blend of the functions described, the benchmark was estimated at 56 functions per hectare. A challenge would be to sustain this level of diversity across the site. However, the diversity benchmark is based upon the capacity of the design to accommodate these functions; it cannot assess the commercial viability of achieving them.

For the second of the four scenarios that was developed for the masterplan, the total floor area of the dwellings has been calculated as 65,529 m². Within the plan 1.45 ha of land has been proposed as green space, as either strategic open space, semi-private gardens around apartment blocks, or as private gardens. Therefore the proportion of green space to the floor area of the dwellings can be calculated as 22 percent. This was slightly below the benchmark proposed by the 'urban house in paradise'. If, however, the open space provided by the canal were included within this value, the proportion of soft landscape would be 29 percent of the total floor area of the dwellings. Whilst it was not proposed that the existing canals be converted to green space, if the new water spaces were green open space instead, the benchmark of 25 percent would be achieved.

The site is 100 percent brownfield. Although it may have been vacant for a number of years, there was no evidence of flora on the site, and therefore it was not thought to provide any habitat. The assessment of the benchmark for the Ecological Significance of the Site requires identification of any water on the site; however this is restricted to ponds, streams and rivers, and does not include manmade canals. As the plan did not propose any alteration to the existing canals, only expanding and improving their condition, it was not thought any detrimental impact on species living within them would be made.

Criteria		Benchmarks
		Ancoats: Urban District
CO2 emissions: inhabitation: kgCO2.m-2.a-1		Assessed in Drawn Study [illegible]
CO2 emissions: On Site Construction Processes: kgCO2.m-2		Assessed in Drawn Study [illegible]
Carbon intensity: kg.kWh-1		Assessed in Drawn Study [illegible]
Conservation period: weeks per dwelling		Assessed in Drawn Study 7
Contextual significance of site: Qualitative		Yes
Deconstruction and demolition: Recycling materials: Percent		Assessed in Drawn Study [illegible]
Design life span: Years		Assessed in Drawn Study 7
Density	quantitative: p.ha-1	395
	qualitative	Yes
Diversity: programmes.ha-1		56
Domestic waste	refuse: kg.p-1.wk-1	Assessed in Drawn Study 7
	recycled: kg.p-1.wk-1	Assessed in Drawn Study 7
Ecological significance of the site: Percent and qualitative		100, Yes and Yes
Ecological weight: embodied energy: kWh.m-2		Assessed in Drawn Study [illegible]
Ecological weight: CO2 emissions: kgCO2.m-2		Assessed in Drawn Study [illegible]
Energy consumption: construction: kWh.m-2		Assessed in Drawn Study [illegible]
Energy consumption: inhabitation: kWh.m-2.a-1		Assessed in Drawn Study [illegible]
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study [illegible]
Green space: Percent		27
Lifecycle cost	Construction: £.m-2.a-1	Assessed in Drawn Study 7
	Energy: £.m-2.a-1	Assessed in Drawn Study 7
	Water: £.p-1.a-1	Assessed in Drawn Study 7
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study [illegible]
Other ecological impacts of materials: Qualitative, g.kWh-1		Assessed in Drawn Study [illegible]
Other greenhouse gas emissions: g.kp-1		Assessed in Drawn Study [illegible]
Pollution: energy consumption inhabitation: g.kWh-1		Assessed in Drawn Study [illegible]
Procurement strategy: Qualitative		Performance spec
Quality of internal environment	indoor pollution: Qualitative	Assessed in Drawn Study 7
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 7
	ventilation: ac.h-1	Assessed in Drawn Study 7
	airtightness: ac.h-1 at 50 Pa	Assessed in Drawn Study 7
Recycling construction waste: Percent		Not Assessed
Adaptability: internal loadbearing walls: Internal walls		Assessed in Drawn Study 7
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	Not Applicable
	3 persons: m2.p-1	Not Applicable
	4 persons: m2.p-1	Not Applicable
	5 persons: m2.p-1	Assessed in Drawn Study 7
	6 persons: m2.p-1	Assessed in Drawn Study 7
	7 persons: m2.p-1	Not Applicable
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
	4 persons: m3.p-1	Not Applicable
	5 persons: m3.p-1	Assessed in Drawn Study 7
	6 persons: m3.p-1	Assessed in Drawn Study 7
	7 persons: m3.p-1	Not Applicable
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance	Roof: W.m-2.K-1	Assessed in Drawn Study 7
	Exposed walls: W.m-2.K-1	Assessed in Drawn Study 7
	Ground and exposed floors: W.m-2.K-1	Assessed in Drawn Study 7
	Windows and rooflights: W.m-2.K-1	Assessed in Drawn Study 7
	Opaque outer doors: W.m-2.K-1	Assessed in Drawn Study 7
Use of recycled materials: Percent		Assessed in Drawn Study [illegible]
Use of renewable raw materials: Percent		Assessed in Drawn Study [illegible]
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Assessed in Drawn Study [illegible]
Water consumption: inhabitation	potable: l.p-1.d-1	Assessed in Drawn Study 7
	rain and grey: l.p-1.d-1	Assessed in Drawn Study 7
	total: l.p-1.d-1	Assessed in Drawn Study 7

Drawn Study Seven



Ancoats: Scale of the Dwelling

Drawn Study Seven

Ancoats: The Scale of the Dwelling

The urban grain of Drawn Study 6 provided the context for the dwelling, within the robust fabric of which a range of dwelling types and sizes could be sited. A house was chosen for the study, as opposed to a flat, for it was considered to present greater challenges in achieving the benchmarks of the 'urban house in paradise'.

The urban grain of the masterplan generated by Drawn Study 6 provided the context for a variety and diversity of dwelling sizes and types, including both flats and houses. Robustness in this plan was intended throughout, to accommodate a wide range of potential demands, and to maximise social inclusion and tenure mix.

The three Studies collectively attempted to test the robustness of the benchmarks proposed for the 'urban house in paradise'; in a flat a number of the benchmarks would be easier to achieve than for a house. For example, the Ecological Weight - Embodied Energy and Embodied CO_2 would be less for a flat than a house, as the energy and CO_2 embodied within the foundations and roof would be shared amongst a number of dwellings in a flat. Also as there would be fewer exposed walls in a flat, particularly on the mid-floors, there would be less heat loss, and therefore the Energy Consumption: Inhabitation and CO_2 Emission: Inhabitation benchmarks would be easier to achieve than for a house. For this reason, the benchmarks were validated through the design of a house, on the premise that if they could be achieved in a house then they are also capable of being achieved in a flat.

Philosophy of the Dwelling

Three terrace dwellings with various frontage widths, and therefore proportions in plan, were designed in outline, from which one was developed into detail. Maximum benefit from daylight and passive solar gain was sought. The phenomenology of cleansing and ascension was studied, the latter especially pertinent in a dwelling with three storeys and a basement; particular attention was paid to the threshold between the dwelling space and the potential workspace on the second floor. Through an

abstraction of a forest into the interior, reference was made to the dwelling as a particularisation of the generic 'urban house in paradise'

A terraced unit was considered most appropriate of the different types of house, both in terms of the context of the site and to maximise the efficiency of land use. These factors also suggested that the dwelling should be at least three storeys in height. Three designs were initially developed, based on five and six inhabitants. The criteria of Space Standards: Area and Volume were used to establish the approximate size of the dwelling, from which the design could evolve. The three dwellings were based on different plot widths, of 6.3, 7.2 and 8.1 metres, to establish a balance between the individual proportions of the dwelling and the overall density of the terrace. The 8.1 metre variant was selected to be developed further for a number of reasons; firstly, because of the proportions of its plan, with a wider frontage and smaller depth, daylight penetration would be greater; secondly, the wider frontage increased the area of glazing available on the front elevation, which faces southeast, and therefore maximised the potential use of solar gains and, again, daylight penetration. In the 6.3 and 7.2 metre variants, once a lobby had been incorporated the aspect from the principal living spaces was limited.

The urban grain was created as a palimpsest of layers, reflecting historical elements within the site, the grain of the surrounding fabric and the desirable east to west axis that can maximise the utilisation of passive solar energy. The dwelling would be sited beside the canal, with a southeast aspect. An attitude verging upon minimalist was taken toward the north wall, which was pierced only where necessity dictates in order to minimise heat loss through this element. A radical distinction was made between that and the southeast elevation, which would present a very different face toward the canal. Much more open in character, maximum use would be made of the sun, both in terms of daylight penetration and passive solar gain.

The entrance lobby of the dwelling was incorporated into the curved frontage of the building, which protruded at ground floor level. Because the dwelling would face southeast, as opposed to due south which would be more desirable, this curve toward the face of the dwelling would reduce overshadow upon the living room window, and maximise the period for which the sun would be visible. The lobby was pulled slightly out to reduce intrusion upon the living spaces.

The timber spokes that would partially separate the staircase from the living spaces on the ground floor were intended, like those in the Villa Mairea by the Finnish architect Alvar Aalto (1898-1976) to represent an abstraction of a forest within the dwelling.[1] This was a reference to Vitruvius' description of the origin of the dwelling as a clearing within a forest; the first house, or Adam's house, is the house in paradise.[2] Portraying the natural environment within the dwelling would also embody the concept of paradise that, within the context of this thesis, represents an ideal, sustainable relationship between the built and the natural environments.

The potential for adaptability would exist throughout the dwelling, which would have no internal load-bearing partitions; the vertical element around which the staircase is laced could provide a structural, in addition to phenomenological, role if necessary. As the staircase would be a fixed element, it was not considered that this would impinge upon the adaptability of the dwelling. The second floor was envisaged as a completely flexible space that could suit many uses and was therefore proposed as free of even non load-bearing partitions. It could act as a master bedroom, or as an apartment within the dwelling for a teenager; in response to the increasing trend of working from home, it could also be used as a workspace. Particularly in the event of the latter, a feeling of phenomenological detachment would be created through the movement from first to second floor. The vertical element that rises through the dwelling, around which the staircase is formed, was intended to emphasise the sense of ascending through increasing the threshold between floors throughout the dwelling. However it would wrap itself around the staircase at the point between first and second floors, to heighten that sense of transition. This would create a psychological as well as physical separation between a potential workspace and the other dwelling spaces. The emotion identified by the French philosopher Gaston Bachelard (1884-1962) associated with climbing the stairs that lead to an attic or garret was also intended to be evoked,

> Lastly, we always *go up* the attic stairs, ... For they bear the mark of ascension to a more tranquil solitude.[3]

The decision was taken, as in Drawn Study 4, to maximise the inhabited volume of the envelope, and therefore to use the space within the pitch of the roof as habitable volume.

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[1] Weston, Richard. *Alvar Aalto*, London: Phaidon Press Limited, 1995.

[2] Reference is made here to Rykwert, Joseph. *On Adam's House in Paradise – The Idea of the Primitive Hut in Architectural History*, Cambridge, Massachusetts: The MIT Press, 1981. Refer to 1.5 in Chapter 1 in volume 1.

This also reflected the comparison drawn between the phenomenological disassociation desired between the space on the second floor and the rest of the dwelling, and Bachelard's description of the emotions associated with the attic as a spatial type. The angle of the roof pitch of the dwelling was generated by balancing the optimal pitch of the photovoltaic array, roughly calculated as 90 minus the latitude of the site although between 30 and 60 degrees is considered acceptable, whilst not creating a large void to heat within the roof pitch. Therefore the pitch was set at 35 degrees.

The asymmetric roof profile was created to maximise the area that had a southern orientation. Therefore the area of the photovoltaic array could be increased if either the energy consumption of the dwelling was increased, requiring additional generation capacity, or the generation was increased so that the dwelling becomes a net supplier of energy, as opposed to the traditional role of consumer.

The principal living spaces were located on the ground floor; above these was a notional layout of bedrooms. The reversal of these two floors was considered. Because heat rises, locating the main living areas above the bedrooms retains heat within the upper, more frequently used, spaces. It would also have enabled a potential connection, through double-height spaces, between the first and second floors, and the living areas could have been distributed across both. However, this proved awkward to realise, due to difficulty in accommodating the sleeping areas, entrance space, bathroom and circulation within the ground floor. It would also have compromised the accessibility of the dwelling to disabled visitors. There would be internal space provision within the kitchen for segregating and storing recyclable material and domestic refuse, where most recyclable material would be produced. Externally there would be a store at the front of the dwelling, and organic putrescible waste could be placed directly onto a compost heap in the rear garden, which could also used to dispose of the odourless produce of the WC composter.

A division of the bathroom into two spaces was implied, through the partial separation of ablutions from the WC. The intention was to create a space within a space that was solely dedicated toward the ritual of cleansing the body. The floor would be gradually inclined, obviating the need for a shower tray, to create the impression that the whole space was predicated to cleansing.

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[3] Bachelard, Gaston. *The Poetics of Space*, Boston: Beacon Press, 1969.

Performance in Use

In the scale of the dwelling, the majority of the benchmarks of the 'urban house in paradise' have been achieved. Where they have not, the amendments to the dwelling that are required in order to do so are identified. Of the ten most significant criteria, all those that relate to this scale are met. Water Consumption: Inhabitation had the greatest deviation from its target, due to insufficient collection surfaces for rainwater.

The most significant benchmark of the 'urban house in paradise', Energy Consumption: Inhabitation was achieved, with a value 24.3 $kWh.m^{-2}.a^{-1}$. However, it required that the thermal performance of the fabric be improved upon beyond the standards of the Thermal Performance benchmark, from 0.13 to 0.10 $W.m^{-2}.K^{-1}$ in the ground floor, to minimise heat loss. The second most significant benchmark, Energy Generation: Inhabitation, was also achieved through an integrated photovoltaic array on the roof, with a value of 25.0 $kWh.m^{-2}.a^{-1}$. Space is included for additional panels if they are required. As the energy generation benchmark was achieved, and exceeds consumption, the net CO_2 Emissions: Inhabitation and Pollution Emissions: Energy Consumption Inhabitation benchmarks were also met. However, because electricity was used throughout the dwelling, the gross values of emissions were not achieved. However, this would only be considered pertinent if 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.

Whilst the overall water consumption benchmark, based upon predicted consumption, was achieved, the rainwater, and therefore mains water, benchmarks were not due to insufficient collection surfaces. It could be speculated that with sufficient storage this factor could be overcome. Alternatively increasing the roof pitch would also increase its area. Whilst this would increase the habitable volume of the dwelling, it would also increase the space to be heated and therefore the energy consumption; this could be resolved by introducing an insulated horizontal ceiling. To accommodate the volume of water storage that would be required for servicing the requirements of the dwelling from rainwater, a basement was proposed. This would be descended into externally, and would be outside the insulated envelope of the dwelling; access is only required for intermittent maintenance. The impact of this upon the overall embodied energy of the dwelling is highlighted in Drawn Study 8.

As established above, three dwellings were designed during the initial stages of the Study, from which the most appropriate was subsequently developed. The 6.3 metre variant was designed to accommodate 5 inhabitants and the 7.2 and 8.1 metre variants to accommodate 6 inhabitants; therefore the Study could only validate the Space Standard: Area and Volume benchmarks for these two occupancies. The space standards of the 8.1 m variant were based upon accommodating 6 people; although it was proposed that the second floor could be used as a workspace, in which case the designed occupancy would be 4. However, as with density, the maximum designed occupancy was used as the basis of the evaluation.

In validating the Space Standards benchmarks, although they were proposed as minimum values for the 'urban house in paradise', concerted effort was made to achieve the benchmarks exactly, and not to increase them. There were two reasons for this. Primarily it was to validate the values themselves; if the dwelling was considered too small for the number of inhabitants it was designed to accommodate, this would suggest that the benchmarks are too low. Aside from the benchmarks, increasing the size of the dwelling would also increase the overall quantity of materials used to construct it, and the total energy that it will consume; this was considered to conflict with the principles of the thesis and therefore of the dwelling. Of lesser significance, it would also increase the overall cost of the dwelling, and therefore reduce its affordability.

The distribution of the dwelling area across three floors, in response to the scale of the urban grain, has meant that the living spaces on the ground floor only occupy approximately one third of the total area of the dwelling, which would be one half if the dwelling were two storeys high. As a consequence of this the living spaces, although larger than a speculative dwelling, appear slightly cramped. This was partly mitigated by the provision of the flexible space on the second floor, which could be used as an additional living space, or as 'bed-sit suite' if the dwelling were occupied by six inhabitants. Another consequence of a three storey dwelling was that area would be lost from the inhabitable space through circulation, due to the additional staircase. As this contributed to the Space Standards value being 3 percent over the benchmark, this suggested the inclusion of a constant within the Space Standards benchmark for dwellings over two storeys.

The standard of the *EcoHomes* assessment for daylight, of a daylight factor of 1 percent in bedrooms, 1.5 percent in living rooms and 2 percent in kitchens, was exceeded.[4] However, with benchmarks of 4.9, 3.5 and 3.5 percent respectively, the performance of the dwelling did not manage to achieve that of the 'urban house in paradise' for the kitchen and living space. The principal reason for this was due to minimising the area of glazing on the north wall to reduce heat loss. To increase the daylight factor to that of the 'urban house in paradise', of 5 percent, would require the area of glazing to be increased by 4 m^2.

Cost

The construction cost of the dwelling was more than double the benchmark of the 'urban house in paradise'. However, the energy cost benchmark achieved by the Drawn Study was an improvement on the target. In combination these values are 17.7 £.m^{-2}.a^{-1} for the Drawn Study and 12.4 £.m^{-2}.a^{-1} for the 'urban house in paradise'. Accounting for an annual increase in fuel prices, the saving in energy costs would equal three-quarters of the cost of the photovoltaic array. Because the potable water consumption of the dwelling could not be reduced to the benchmark of the 'urban house in paradise', for the reasons outlined above, the lifecycle water cost benchmark could also not be achieved.

The construction cost for the dwelling was estimated by the quantity surveyors Davis Langdon Everest at a total of £175,300 or 1,386.76 £.m^{-2}. Davis Langdon and Everest also costed a variation excluding the basement and water saving appliances at 1,200.06 £.m^{-2}; these values would equate to 11.56 and 10.00 £.m^{-2}.a^{-1} across the life span of the dwelling. The summary of the cost estimate is included at the end of this Drawn Study. These are both more than double the benchmark of construction cost for the 'urban house in paradise', of 4.44 £.m^{-2}.a^{-1}.

The first year energy costs of the dwelling without renewable generation were calculated, based on the predicted energy consumption; this equated to £168 per annum. Also analysed were the energy costs if the consumption were that of a typical dwelling; this would equate to £687, giving an annual reduction of £486. Ignoring the annual increase of fuel prices, this would equate to a saving of £62,263 over the life span of the dwelling. The full cost of the photovoltaic array was estimated at £10,000; the accepted life span of which is

[4] British Standards Institute. *BS 8206: Part 2: 1992 - Lighting for Building Codes of Practice for Daylighting*, London: HMSO, 1992.

25 years[5] and therefore might have to be replaced up to four times. As the generation capacity of the array would roughly balance the energy consumption, the annual saving of £168 would not finance the cost of the photovoltaics, although the saving over that of the typical consumption level would. However, this does not account for additional construction cost of reducing the consumption to below 25 $kWh.m^{-2}.a^{-1}$.

A spreadsheet was used to calculate the cost of energy consumption including an annual price increase. The total value of 7.36 $£.m^{-2}.a^{-1}$ was an improvement upon the benchmark of the 'urban house in paradise', of 7.96 $£.m^{-2}.a^{-1}$. The same spreadsheet was also used to estimate the energy costs that would be incurred by the dwelling over a 25 year period, the design life span of the photovoltaic array, if the dwelling used mains electricity instead of renewable; it was calculated as £7,326.72. This sum would cover three-quarters of the initial installation costs of the array identified above. Also analysed were the energy costs if the consumption were that of a 'typical,' dwelling, of 194 $kWh.m^{-2}.a^{-1}$; this equated to 19.30 $£.m^{-2}.a^{-1}$. Therefore, the saving over the life span of the dwelling, including annual increase, could be predicted as £181,148.90, more than twice the capital construction cost of the dwelling.

The potable water consumption of the dwelling is 28.92 $l.p^{-1}.d^{-1}$. The cost estimate showed that the predicted water costs across the life span of the dwelling would be 123.95 $£.p^{-1}.a^{-1}$. If the typical benchmark level, of 160 litres per person per day, were consumed the cost would be 359.80 $£.p^{-1}.a^{-1}$; over the life span of the dwelling, this would equate to a fiscal cost saving of £28,302 per person, or £67,925 based on the mean occupancy figure of 2.4 people.

Therefore whilst the lifecycle energy cost of the dwelling improved upon the benchmark of the 'urban house in paradise', both the construction cost and the water costs did not. The latter was primarily due to the roof area being insufficient to provide adequate collection for rainwater to reduce the mains consumption to the target benchmark. However, the cost saving from the reduced mains consumption exceeded the additional construction cost of creating the basement to store the water in.

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[5] Roaf, Dr Susan. Lecturing at 'Sustainability in Building Design' seminar, University College, Chester, on 18 August 1999. This value is used as a minimum; there is contention over this figure, as the productive life of photovoltaic panels and their degradation over time has not been conclusively studied.

There is existing residential development in the vicinity of the site. The sales prices for these were studied, to establish the margin between the construction cost of the dwelling and the potential sales value that it might have; this would exclude any potential added value in the low running costs of the dwelling. Wharf Apartments are located beyond the southeast edge of the site, slightly further from the city centre; the mean sale price is 1,440 £.m^{-2}. Piccadilly Lofts are based on the southwest edge of the site, just across Dale Street, for which the mean sale price is 2,588 £.m^{-2}. Whilst it was a simplistic comparison, based upon two different dwelling types, and therefore different lifestyles, the areas of the larger Piccadilly Loft apartments were very comparable to that of the Drawn Study dwelling, between 106 and 142 m^2, with one at 124 m^2, the Space Standard benchmark. The mean value of sale costs in the area was, therefore, 2,014 £.m^{-2}. If this could be applied to the dwelling, the margin for land cost and profit would be £79,283.

The performance of the Drawn Study in terms of the criteria of the 'urban house in paradise' can be seen in the table overleaf.

Criteria		Benchmarks
		Ancoats: Scale of the Dwelling
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		Assessed in Drawn Study 8
CO2 emissions: On Site Construction Processes: kgCO2.m-2		Assessed in Drawn Study 8
Carbon intensity: kg.kWh-1		Assessed in Drawn Study 8
Construction period: weeks per dwelling		6
Contextual significance of site: Qualitative		Assessed in Drawn Study 6
Deconstruction and demolition: Recycling materials: Percent		Assessed in Drawn Study 8
Design life span: Years		120
Density:	quantitative: p.ha-1	Assessed in Drawn Study 6
	qualitative	Assessed in Drawn Study 6
Diveristy: programmes.ha-1		Assessed in Drawn Study 6
Domestic waste:	refuse: kg.p-1.wk-1	2.4
	recycled: kg.p-1.wk-1	7.2
Ecological significance of the site: Percent and qualitative		Assessed in Drawn Study 6
Ecological weight: embodied energy: kWh.m-2		Assessed in Drawn Study 8
Ecological weight: CO2 emissions: kgCO2.m-2		Assessed in Drawn Study 8
Energy consumption: construction: kWh.m-2		Assessed in Drawn Study 8
Energy consumption: inhabitation: kWh.m-2.a-1		Assessed in Drawn Study 8
Energy generation: kWh.m-2.a-1		Assessed in Drawn Study 8
Green space: Percent		Assessed in Drawn Study 6
Lifecycle cost:	Construction: £.m-2.a-1	11.56
	Energy: £.m-2.a-1	7.36
	Water: £.p-1.a-1	124.0
Nitrogen oxide emissions: mg.kWh-1		Assessed in Drawn Study 8
Other ecological impacts of materials: Qualitative, g.kWh-1		Assessed in Drawn Study 8
Other greenhouse gas emissions: g.kg-1		Assessed in Drawn Study 8
Pollution: energy consumption inhabitation: g.kWh-1		Assessed in Drawn Study 8
Procurement strategy: Qualitative		Performance spec
Quality of internal environment:	indoor pollution: Qualitative	Yes
	daylight: living, kitchen, beds: Percent	3.5, 3.5, 4.9
	ventilation: ac.h-1	0.45
	airtightness: ac.h-1 at 50 Pa	0.17
Recycling construction waste: Percent		Not Assessed
Adaptability: Internal loadbearing walls: Internal walls		0
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	Not Applicable
	3 persons: m2.p-1	Not Applicable
	4 persons: m2.p-1	Not Applicable
	5 persons: m2.p-1	21.6
	6 persons: m2.p-1	21.1
	7 persons: m2.p-1	Not Applicable
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
	4 persons: m3.p-1	Not Applicable
	5 persons: m3.p-1	64.8
	6 persons: m3.p-1	70.6
	7 persons: m3.p-1	Not Applicable
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance:	Roof: W.m-2.K-1	0.08
	Exposed walls: W.m-2.K-1	0.12
	Ground and exposed floors: W.m-2.K-1	0.10
	Windows and rooflights: W.m-2.K-1	0.80
	Opaque outer doors: W.m-2.K-1	0.55
Use of recycled materials: Percent		Assessed in Drawn Study 8
Use of renewable raw materials: Percent		Assessed in Drawn Study 8
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		Assessed in Drawn Study 8
Water consumption: inhabitation:	potable: l.p-1.d-1	25.4
	rain and grey: l.p-1.d-1	12.9
	total: l.p-1.d-1	38.3

Benchmark performance of Drawn Study 7

Job Nr 18859

ENVIRONMENTALLY FRIENDLY DWELLING

for MR. C R SMITH

COST PLAN NR 1 – OPTION 1

Davis Langdon & Everest
Chartered Quantity Surveyors
Duncan House
14 Duncan Street
Leeds
LS1 6DL

Author:	DJG
Approver:	CAB
Revision:	0
Issue Date:	7 December 2000

1.0 The Cost Plan is based upon the following information:-

C R Smith Drawings -	Masterplan	1:1250
	Dwelling Plan & Sections	1:50
	Ground Floor	1:20
	First Floor	1:20
	Second Floor	1:20
	Cross Section	1:20
	Long Section	1:20

C R Smith fax dated 2 October 2000 – Enclosing revised basement sketches
C R Smith fax dated 11 October 2000 – Response to queries
C R Smith fax dated 1 November 2000 – Response to queries
C R Smith fax dated 22 November 2000 – Response to queries

2.0 The costs included are based upon fourth Quarter 2000 (4Q00) pricing levels and assume a traditional competitive lump sum tender. The house unit will form part of a larger contract for up to 37 units of accommodation to similar standards and specification and the pricing levels adopted reflect this volume of work.

3.0 The costs included in the Cost Plan exclude the following:

- Site acquisition and associated costs, including land, legal fees, agents commissions etc.
- Abnormal ground conditions (other than those described) – assumes land is contaminated only so far as removing tarmac to a licensed tip.
- Effect of discovery of archaeological artefacts or other antiquities.
- Abnormal service provisions or connection costs.
- Allowance for specialist external works.
- Building Control and Planning Application Fees.

- Furniture, fittings and equipment beyond that referred to in the detailed estimate.
- Professional Fees.
- VAT.
- Future inflation in tender price levels.

4.0 The measurements contained in this Cost Plan have been prepared in accordance with The Standard Form of Cost Analysis (Principles Instructions and Definitions) published by BCIS, December 1969 (reprinted July 1973) and shall not be relied upon for any purpose other than the formulation of the cost plan.

Element	%	Cost £/M2	Total £	Notes
1 SUBSTRUCTURE	6.90	71.60	12,100	
2 SUPERSTRUCTURE				
2A Frame				
2B Upper Floors	2.45	25.44	4,300	
2C Roof	12.04	124.85	21,100	
2D Stairs	1.20	12.43	2,100	
2E External Walls	15.74	163.31	27,600	
2F Windows and External Doors	11.58	120.12	20,300	
2G Internal Walls & Partitions	11.69	121.30	20,500	
2H Internal Doors	0.68	7.10	1,200	
3 FINISHES				
3A Wall Finishes	0.57	5.92	1,000	
3B Floor Finishes	2.91	30.18	5,100	
3C Ceiling Finishes	0.68	7.10	1,200	

Element	%	Cost £/M2	Total £	Notes
4 FITTINGS & FURNISHINGS	2.85	29.59	5,000	
5 SERVICES				
5A Sanitary Appliances	2.62	27.22	4,600	
5B Services Equipment				
5C Plumbing & Disposal Installations	0.46	4.73	800	
5D Water Installations & Piped Services	6.10	63.31	10,700	
5E Heating and Mechanical Services	2.97	30.77	5,200	
5F Electrical Installations	1.60	16.57	2,800	
5G Gas Installation				
5H Special Installations	0.97	10.06	1,700	
5I Builder's work in connection				
6 EXTERNAL WORKS				
6A Site Work	0.86	8.88	1,500	
6B Drainage	0.97	10.06	1,700	

Element	%	Cost £/M2	Total £	Notes
6C External Services	0.68	7.10	1,200	
			151,700	
PRELIMINARIES - 10%	8.67	89.94	15,200	
			166,900	
CONTINGENCIES AND DESIGN RESERVE - 5%	4.79	49.70	8,400	
Total Carried to Summary	**100.00**	**1037.28**	**175,300**	

Drawn Study Seven

The urban grain of Drawn Study 6 provided the context for the dwelling, within the robust fabric of which a range of dwelling types and sizes could be built. A house was chosen for the study, as opposed to a flat, for it was considered to present greater challenges in achieving the benchmarks of the 'urban house in paradise'.

The urban grain of the masterplan generated by Drawn Study 6 provided the context for a variety and diversity of dwelling sizes and types, including both flats and houses. Robustness in this plan was intended throughout, to accommodate the wide range of potential demands, and to maximise social inclusion and tenure mix.

The three studies collectively attempted to test the robustness of the benchmarks proposed for the 'urban house in paradise'; in a flat a number of the benchmarks would be easier to achieve than for a house. For example, the Ecological Weight - Embodied Energy and Embodied CO_2 would be less for a flat than a house, as the energy and CO_2 embodied within the foundations and roof would be shared amongst a number of dwellings in a flat. Also as there would be fewer exposed walls in a flat, particularly on the mid-floors, there would be less heat loss, and therefore the Energy Consumption: Inhabitation and CO_2 Emission: Inhabitation benchmarks would be easier to achieve than for a house. For this reason, the benchmarks were validated through the design of a house, on the premise that if they could be achieved in a house then they are also capable of being achieved in a flat.

Philosophy of the Dwelling

Three terrace dwellings with various frontage widths, and therefore proportions in plan, were designed in outline, from which one was developed in detail. The phenomenology of cleansing and ascension was studied. Through an abstraction of a forest into the interior, reference was made to the dwelling as a particularisation of the generic 'urban house in paradise'

A terraced unit was considered most appropriate of the different types of house, both in terms of the context of the site and to maximise the efficiency of land use. These factors also suggested that the dwelling should be at least three storeys in height. Three designs were initially developed, based on five and six inhabitants. The criteria of Space Standards: Area and Volume were used to establish the approximate size of the dwelling, from which the design could evolve. The three dwellings were based on different plot widths, of 6.3, 7.2 and 8.1 metres, to establish a balance between the individual proportions of the dwelling and the overall density of the terrace. The 8.1 metre variant was selected to be developed further for a number of reasons; firstly, because of the proportions of its plan, with a wider frontage and smaller depth, daylight penetration would be greater; secondly, the wider frontage increased the area of glazing available on the front elevation, which faces southeast, and therefore maximised the potential use of solar gains and, again, daylight penetration. In the 6.3 and 7.2 metre variants, once a lobby had been incorporated the aspect from the principal living spaces was limited.

The entrance lobby of the dwelling was incorporated into the curved frontage of the building, which protruded at ground floor level. Because the dwelling would face southeast, as opposed to due south which would be more desirable, this curve toward the face of the dwelling would reduce overshadow upon the living room window, and maximises the period for which the sun would be visible. The lobby was pulled slightly out to reduce intrusion upon the living spaces.

The principal living spaces were located on the ground floor; above these was a traditional layout of bedrooms. The reversal of these two floors was considered. Because heat rises, locating the main living areas above the bedrooms retains heat within the upper, more frequently used, spaces. It would also have enabled a potential connection, through double-height spaces, between the first and second floors, and the living areas could have been distributed across both. However, this proved awkward to realise, due to difficulty in accommodating the sleeping areas, entrance space, bathroom and circulation within the ground floor. It would also have compromised the accessibility of the dwelling to disabled visitors. There would be internal space provision for recycling storage within the kitchen, where most recyclable material would be produced. Externally there would be a store at the front of the dwelling, and organic putrescible waste could be placed directly into a compost heap in the rear garden, which could also be used to dispose of the odourless produce of the WC composter.

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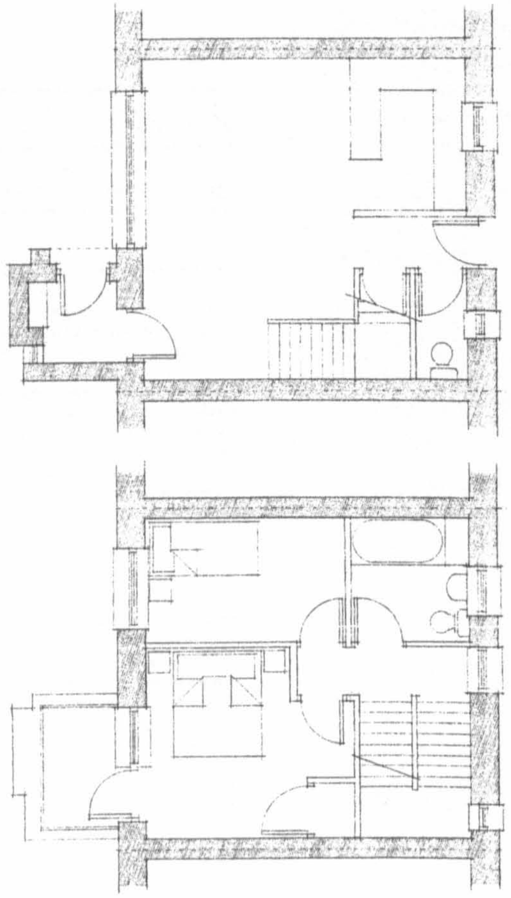
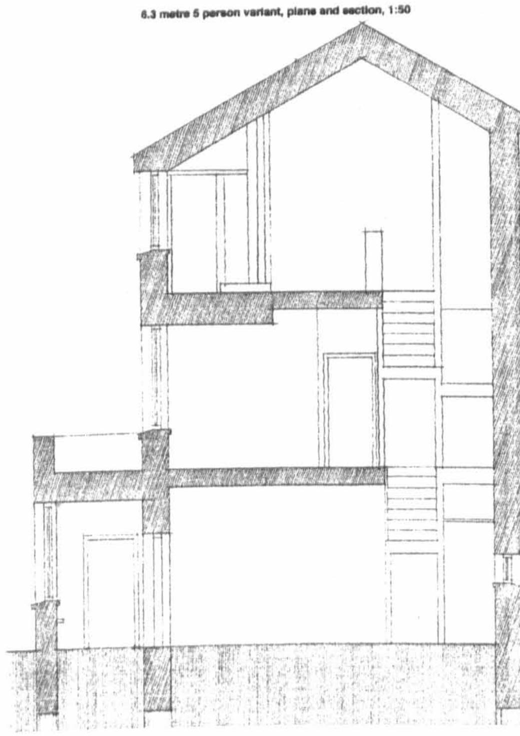
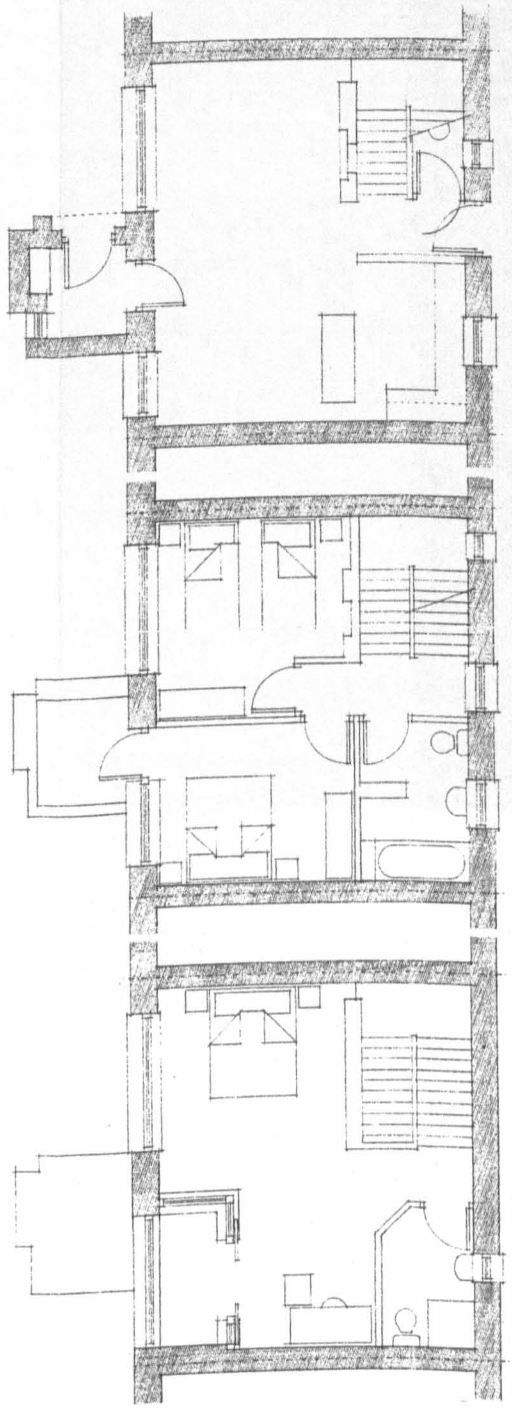
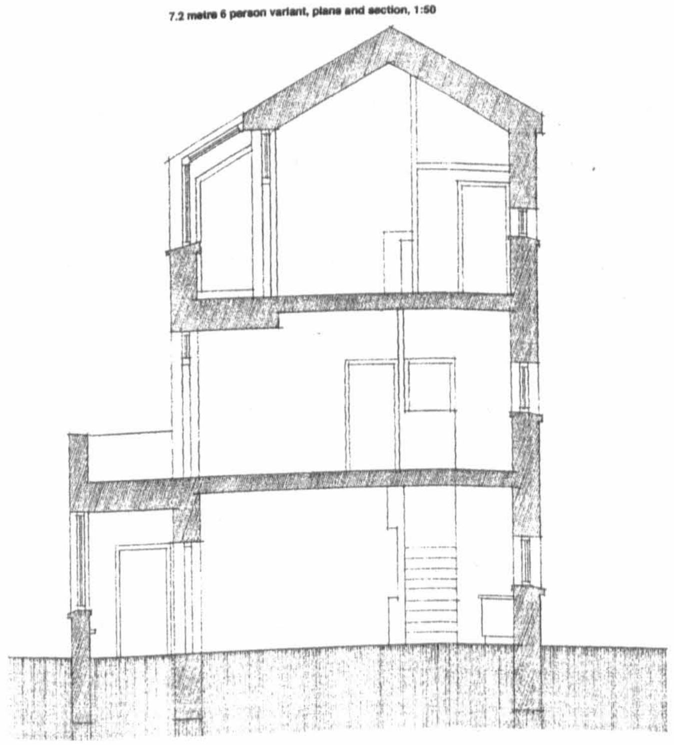


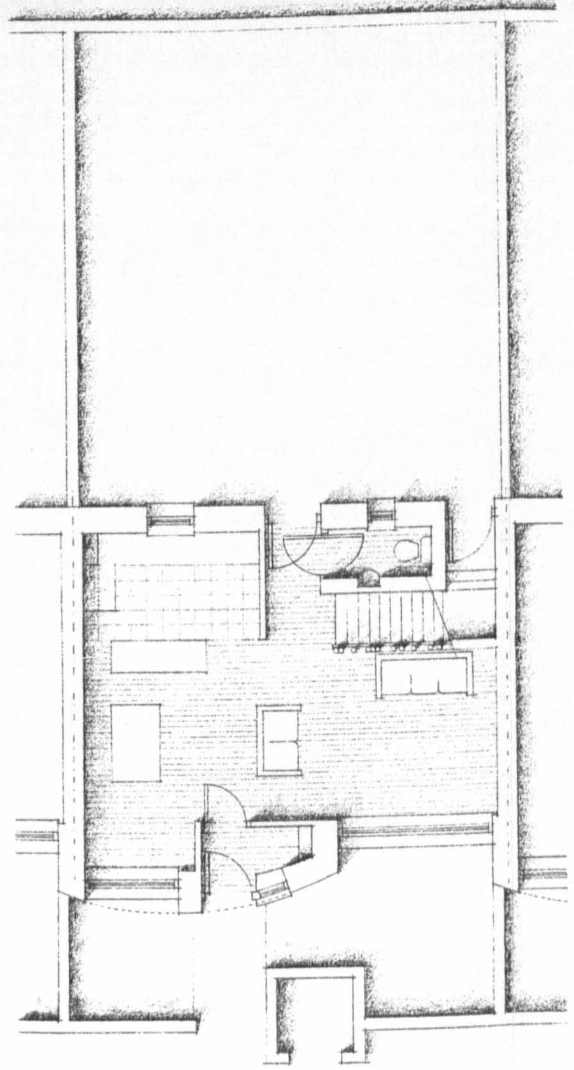


6.3 metre 5 person variant, plans and section, 1:50



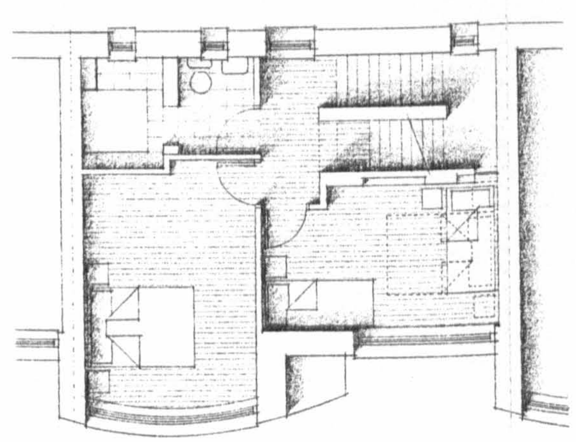


7.2 metre 6 person variant, plans and section, 1:50

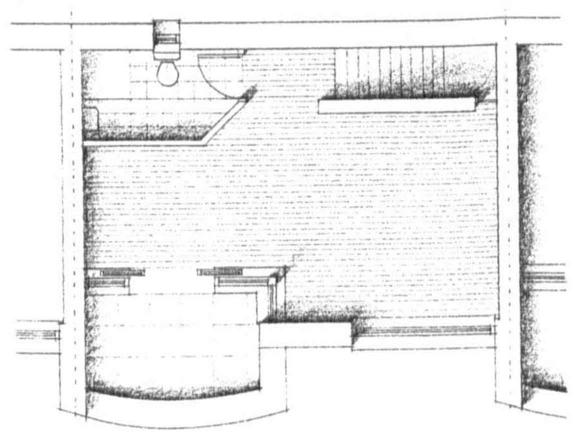


8.1 metre 6 person variant, 1:50

Ground floor



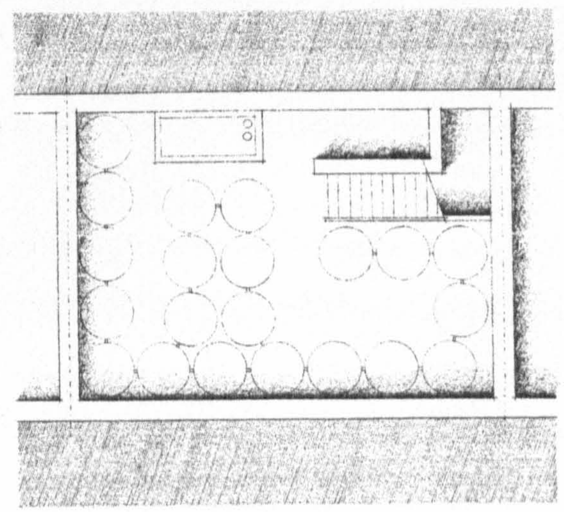
First floor



Second floor

Ancoats: Scale of the Dwelling

The potential for adaptability would exist throughout the dwelling, which would have no internal load-bearing partitions; the vertical element around which the staircase is laced could provide a structural, in addition to phenomenological, role if necessary. As the staircase would be a fixed element, it is not considered that this would impinge upon the adaptability of the dwelling. The second floor was envisaged as a completely flexible space that could suit many uses and was therefore proposed as free of even non load-bearing partitions. It could act as a master bedroom, or as an apartment within the dwelling for a teenager; in response to the increasing trend of working from home, it could also be used as a workspace.



Basement

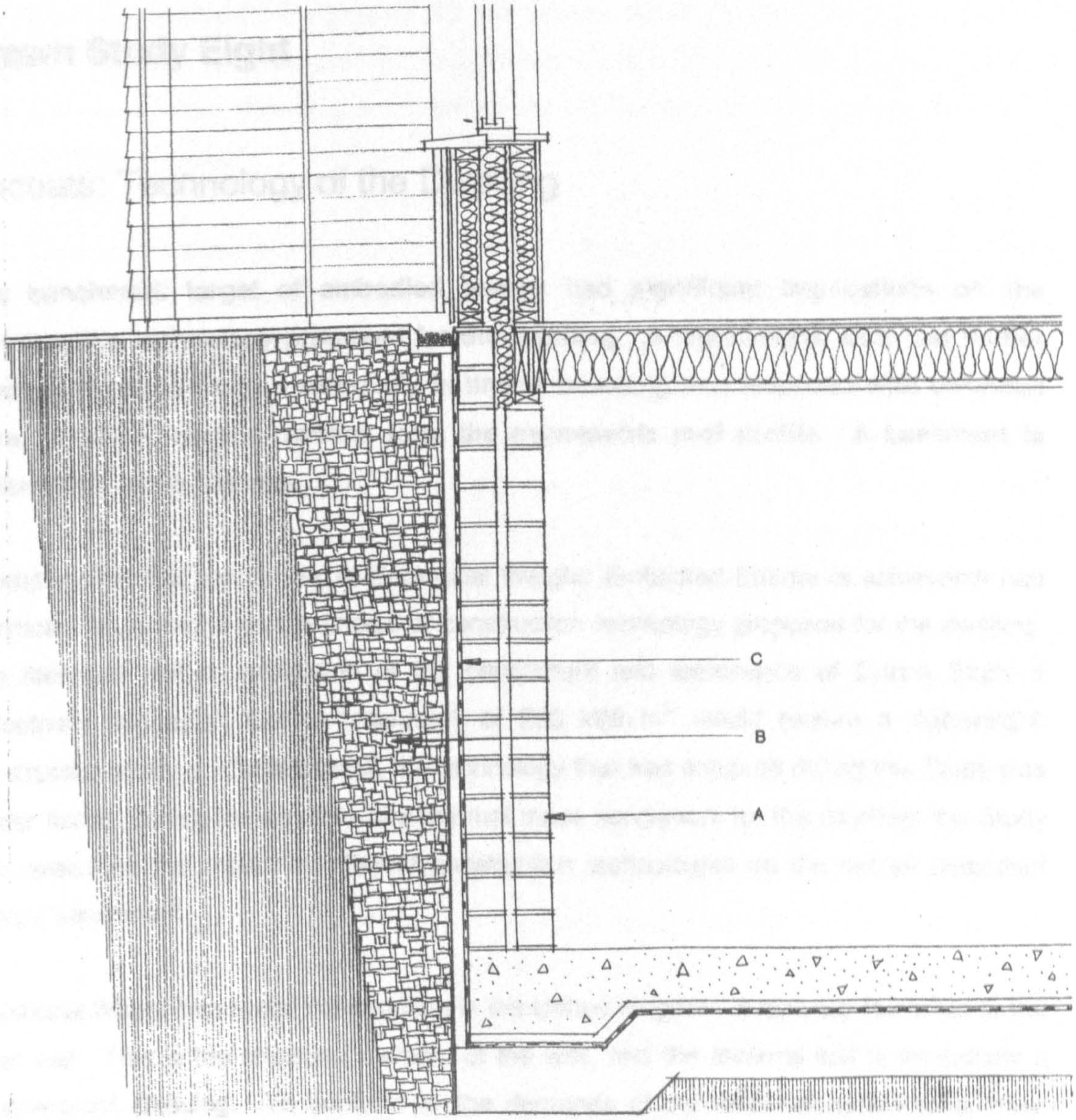
A division of the bathroom into two spaces was implied, through the partial separation of ablutions from the WC. The intention was to create a space within a space that was solely dedicated toward the ritual of cleansing the body. The floor would be gradually inclined, obviating the need for a shower tray, to create the impression that the whole space was predicated to cleansing.

As established above, three dwellings were designed during the initial stages of the Study, from which the most appropriate was subsequently developed. The 6.3 metre variant was designed to accommodate 5 inhabitants and the 7.2 and 8.1 metre variants to accommodate 6 inhabitants; therefore the Study could only validate the Space Standard: Area and Volume benchmarks for these two occupancies. The space standards of the 8.1 m variant were based upon accommodating 6 people; although it was proposed that the second floor could be used as a workspace, in which case the designed occupancy would be 4. However, as with density, the maximum designed occupancy was used as the basis of the evaluation.

In validating the Space Standards benchmarks, although they were proposed as minimum values for the 'urban house in paradise', concerted effort was made to achieve the benchmarks exactly, and not to increase them. There were two reasons for this. Primarily it was to validate the values themselves; if the dwelling was considered too small for the number of inhabitants it was designed to accommodate, this would suggest that the benchmarks are too low. Aside from the benchmarks, increasing the size of the dwelling would also increase the overall quantity of materials used to construct it, and the total energy that it will consume; this was considered to conflict with the principles of the thesis and therefore of the dwelling. Of lesser significance, it would also increase the overall cost of the dwelling, and therefore reduce its affordability.

The distribution of the dwelling area across three floors, in response to the scale of the urban grain, has meant that the living spaces on the ground floor only occupy approximately one third of the total area of the dwelling, which would be one half if the dwelling were two storeys high. As a consequence of this the living spaces, although larger than a speculative dwelling, appear slightly cramped. This was partly mitigated by the provision of the flexible space on the second floor, which could be used as an additional living space, or as 'bed-sit suite' if the dwelling were occupied by six inhabitants. Another consequence of a three storey dwelling was that area would be lost from the inhabitable space through circulation, due to the additional staircase. As this contributed to the Space Standards value being 3 percent over the benchmark, this suggested the inclusion of a constant within the Space Standards benchmark for dwellings over two storeys.

Drawn Study Eight



Ancoats: Technology of the Dwelling

Drawn Study Eight

Ancoats: Technology of the Dwelling

The benchmark target of embodied energy had significant implications on the construction technology proposed for the dwelling. A 'lightweight' dual leaf timber frame wall would be clad externally in timber boarding and insulated with cellulose fibre. Timber I-section 'rafters' form the asymmetric roof profile. A basement is included for water storage.

Validating that the benchmark of Ecological Weight: Embodied Energy is achievable had significant implications on the choice of construction technology proposed for the dwelling. The literature review, evaluation of the benchmark and experience of Drawn Study 5 collectively suggested that a benchmark of 250 $kWh.m^{-2}$ would require a 'lightweight' construction method. On this basis, the technology that was explored during this Study was timber frame. During the analysis of a thermal mass benchmark for the dwelling, the Study also evaluated the impact of different construction technologies on the overall embodied energy benchmark.

Traditional timber frame wall construction in the United Kingdom is typically restricted to the inner leaf. This is the structural element of the wall, and the external leaf is essentially a weatherproof cladding. To conform to the demands of conventional appearance, most house builders use an outer leaf of brick or rendered concrete block; this was not considered appropriate, especially brick, due to the embodied energy target benchmark. Therefore a dual leaf of timber frame was proposed; this had the additional advantage that timber has a low value of thermal conductivity, of 0.14 $W.m^{-1}.K^{-1}$ as opposed to that of brick of 1.21 $W.m^{-1}.K^{-1}$. Furthermore, insulation could be in-filled between the studs, which, in relative terms, would create a high thermal performance in respect to the thickness of the element.

The dual leaf walls would have studs at 600 mm centres; these would be staggered between the panels to reduce the width of timber, and therefore increase that of the insulation, at any point in the wall. Each panel and the 100 mm cavity between them would be filled with Warmcel's 'Fibretherm K' cellulose fibre insulation. To reflect the structure of the dwelling, the external cladding of the wall panels would be timber shiplap horizontal boarding. Vertical battens would be fixed to the studs in the outer leaf, between which would be the plywood sheathing and breather membrane; therefore the battens would hold the membrane in place.

Two construction strategies would be possible. Each leaf could be prefabricated and transported to site individually. However, it would be more desirable if the wall panel was constructed as a single sandwich element with both leaves and the cavity pre-filled with insulation, which could also have the external cladding fitted to the outside leaf, and brought to site as one element. The largest panel would be 8.1 metres wide and a single storey high. The windows and services within the walls, such as electrical sockets and light switches, would also be prefabricated into the panels. This strategy would be beneficial both in terms of reducing transportation and the construction period.

Because the windows and doors are, in comparison to the rest of the wall element, poor in terms of thermal performance, the highest standard that could be determined was specified. Within the United Kingdom the best performance that could be established was a Swedhouse UK window, triple glazed with low emissivity coatings and krypton gas fill, with a U-value of 0.95 $W.m^{-2}.K^{-1}$. Quadruple glazed Canadian windows, with low emissivity coatings, krypton gas fill and insulated spacers, have a performance of 0.73 $W.m^{-2}.K^{-1}$, but would have more embodied energy as they are manufactured outside the United Kingdom. The Ekstrands Ekodoor has a U-value of 0.55 $W.m^{-2}.K^{-1}$.

The space required for the storage of collected rainwater, a consequence of the Water Consumption: Inhabitation benchmark, would necessitate the excavation of a basement. The depth would be kept to a minimum to reduce the quantity of material generated. The internal faces, including the party wall, would be constructed from Thermalite concrete blocks; these would provide the base upon which to stand the timber frame external walls. The basement floor would be an in-situ concrete slab; as the ground conditions are unknown, a basic strip foundation beneath the block walls was assumed. The external face of the basement walls would be tanked, which would be protected by a layer of hardboard; backfill of broken brick from the demolition of the existing buildings on site, which are not contextually significant in terms of their materiality, would ensure good drainage. To some extent the inclusion of the basement was justified, as the clearance of the site and probable remediation, due to the former occupation of the site by warehouses, would require a degree of excavation, although not as extensive. The implications of including the basement upon the overall embodied energy of the dwelling are discussed below.

As the basement would be outside the heated envelope of the dwelling, the timber ground floor would be underlined with plywood, fixed back to the joists. Warmcel insulation would then be laid between the joists before the timber floorboards are laid across the top. The entrance to the basement would also be external to the heated envelope, and therefore the underside of the staircase between ground and first floor and the vertical element around which it wraps would also be insulated. The first and second floors would be constructed from timber joists and floorboards, but underlined with plasterboard.

To create the depth of roof structure required to accommodate 600 mm of insulation timber I-section beams were proposed at 600 mm centres; these would be constructed with a plywood web and 50 by 100 mm softwood flanges. Timber noggins would give these lateral bracing, and prevent the insulation sinking to the eaves and therefore reducing the thermal performance of the roof at its apex.[1] Plywood panels would sheathe either side of the I-sections to contain the insulation, and therefore the roof could be prefabricated. On the internal side timber battens would create a cavity between the plywood and fireboard face, within which wiring can be run to light fittings. This means that the air membrane, which would be behind the plywood sheathing, would not have to be pierced by services. This is another advantage of using the space under the roof pitch within the inhabited volume, because all services would be kept within the insulated skin of the dwelling. If, for example, the water tank were located within the unheated roof void, the pipes would then have to pass through the insulation and, therefore, the air membrane.

The outside face of the roof would be tiled. Ideally the tiles would be recycled from existing buildings on the site, before they are demolished. Should this not prove possible, or be insufficient in quantity, slates from another site within close proximity would be sought. The photovoltaic array would be integrated into the roof, on the southeast elevation. This was arranged to run from the ridge down to eaves, and therefore would require careful detailing at the ridge. The sub-frame for the array would be carried on the horizontal roof battens; the

[1] Robert and Brenda Vale use a similar technology for their dwelling in Southwell, from where this technology for the roof is adopted. Vale, Brenda and Robert. *The New Autonomous House – Design and Planning for Sustainability*, London: Thames & Hudson Limited, 2000.

frame would run up the roof pitch, creating a 25 mm air cavity behind the panels to ventilate them.[2]

A structural engineer reviewed the proposals for the construction technology of the dwelling, and considered that no structural problems were present.[3]

Air Tightness

The strategy to achieve the air tightness benchmark was based upon precedent. An air membrane would line each element of the dwelling's envelope, which would be carefully sealed at the junctions between elements. Details for sealing openings within the envelope were also proposed.

Because the value of the air tightness can only be validated after completion of the dwelling, the strategy adopted in the design of the dwelling was to base the detailing on precedents that have demonstrated similar performance to the benchmark target. 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,[4] which is the benchmark of the 'urban house in paradise'. This dwelling was built using a similar construction technology. Dual leaf timber frame walls had and overall insulation thickness of 300 mm, and were finished externally in timber cladding; floors were suspended timber; windows were double glazed in timber frames. The roof was structural timber, with 350 mm insulation in the plane of the pitch. This dwelling proves that the benchmark target is achievable using timber frame construction.

The principle strategy for achieving the target of air tightness would be a 'Monarflex Multifilament 250' air membrane that would line the internal face of the roof, walls and ground floor on the warm side of the insulation. As described above, in the roof the membrane would be behind the inner layer of plywood sheathing. The air membrane must be continuous throughout the dwelling, and therefore creating the joints between the roof, wall and floor elements is crucial. The membrane in the wall would line the inner face of the internal leaf; at the top of the wall the barrier would be brought over the top of plasterboard. Where the roof and wall meet the two membranes would be taped and sealed together

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[2] Roaf, Dr Susan. Lecturing at 'Sustainability in Building Design' seminar, University College, Chester, on 18 August 1999.
[3] Personal communication with Stephen Bandy of Dewhurst McFarlane, 28 November 2000.

using Monobond tape, and fixed back behind a plaster stop bead. The layer of plaster skimmed over the top would provide an additional airtight layer. A similar strategy would be used at the junctions between external and party walls, and walls and the ground floor.

The openings for windows and doors would be another potential source of infiltration. The strategy adopted in Drawn Study 5 for sealing openings would be equally, possibly more, suited to a timber frame dwelling. A plywood surround would trim the opening to which the membrane would be taped and sealed; a silicone sealant between the plywood and the interior of the wall would ensure that the openings were sealed into the external envelope. Non-CFC foam sprayed between the back of the window frame and the plywood surround would ensure that the element is sealed into the opening. As the windows and doors themselves are constructed to a very high performance standard, where panes can be opened they have a high quality in-built seal to minimise air leakage when they are closed.

Energy Consumption and Ventilation

Both the Energy Consumption and Energy Generation benchmarks were achieved, the former had implications on the choice of heating system that was specified for the dwelling. The very high standard of air tightness demanded a strategy for adequately ventilating the dwelling. These two demands were reconciled by a Genvex 'Combi' unit, providing warm air mechanical ventilation with heat recovery.

The energy consumption of 10.2 $kWh.m^{-2}.a^{-1}$ for space and water heating, is an improvement upon Drawn Study 5. An efficient scenario was assumed for the consumption of lights and appliances; the former would be achieved through the use of compact florescent light fittings. The overall Energy Consumption: Inhabitation benchmark was calculated as 24.3 $kWh.m^{-2}.a^{-1}$. This was fractionally below the benchmark of the 'urban house in paradise'.

With a very high standard of air tightness, a strategy of ventilating the dwelling that would ensure an adequate supply of fresh air was required. It was proposed that, rather than using two independent systems for heating and ventilation, the Genvex warm air mechanical ventilation system with heat recovery would also be appropriate for Drawn Study 8. The

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

Genvex 'Combi' unit, which has an integral hot water supply, would be located within an accessible void over a horizontal ceiling in the en-suite WC on the second floor, but within the insulated envelope. The vertical ducts would run through the dwelling in the rear left hand corner, and horizontally through the floors. With the very low space heating demand, it was considered that supplementary heating over and above that provided by the Genvex system would not be required.

Design Life Span

The life span was a design target benchmark. Whilst careful detailing should ensure that the timber frame would achieve the benchmark, the external cladding would have to be replaced. The life span of this was established as 30 years, and the replacement over the life span of the dwelling incorporated into the embodied energy calculations.

The decision to use timber frame construction, largely influenced by the Ecological Weight and also the Use of Renewable Materials benchmarks, raised the issue of the life expectancy of the structure. For masonry construction the Design Life Span benchmark does not prove onerous; the mean life expectancy of facing brickwork of 105 years and the maximum of 300 years would suggest that the construction technology would not require significant innovation to ensure a life span of 120 years. Under the British Standards any timber frame dwelling would be required to achieve a design life expectancy of 60 years. The Timber Research and Development Association (TRADA) consider that under the correct conditions, achieving a life span of 120 years would not present difficulties;[5] there are examples of timber frame buildings that exemplify this is possible. The critical factor would be quality of detailing, and in two areas in particular. The first is around junctions and openings to ensure that moisture would be shed from the fabric and would not collect, causing rot. Secondly, a cavity should be provided between the external skin and the breather membrane that would allow any moisture to escape or evaporate. This was proposed within the Drawn Study, created by the vertical battens to which the external boarding would be fixed.

[5] Personal communication with technical representatives of Timber Research and Development Association, 1 August 2000.

It was accepted that the external boarding would not be sufficiently durable to last for the design life span of 120 years; it would essentially be a sacrificial layer. Once the life expectancy of the boarding was determined, it could be used within the embodied energy calculation to determine the impact of its replacement upon the embodied energy throughout the life span of the dwelling.

The specification would be for a naturally durable species such as Douglas Fir, which is grown in the United Kingdom. Western Red Cedar is a more common timber cladding material in the United Kingdom, and is more durable than Douglas Fir; however, as it comes only from North America it would not comply with the Other Ecological Impacts of Materials and Use of Local Resources benchmarks, and would significantly increase the embodied energy of the cladding. In Sunley and Bedding, Douglas Fir is classed as 'moderately durable', with a predicted life span of 10 to 15 years, for timber in contact with the ground. It was noted that timber used externally and not in contact with the ground, even if untreated, would have a longer life than that given.[6] It was assumed that as the cladding fulfils these latter criteria, and as it would be treated, the life expectancy could be extended to 30 years. This value is borne out by the Royal Institution of Chartered Surveyors' *Life Expectancies of Building Components*, which gives a mean value of 33 years for weather boarding; the maximum predicted is 150 years which would last the design life span of the dwelling, however 30 years was taken as a conservative estimate.[7]

Water Consumption

The predicted water consumption achieved the overall benchmark. However, despite the inclusion of adequate storage in a basement, the roof proved insufficient to provide the area of collection surfaces required for harvesting rainwater. Therefore the potable water consumption was exceeded in fulfilling the shortfall.

Achieving the water consumption benchmark would depend on the predicted water consumption of the dwelling. This can be determined by analysing the probable consumption based on typical inhabitation patterns over the course of one week, which is studied in detail in the Water Consumption: Inhabitation benchmark analysis in Annexe 3.37,

[6] Sunley, John and Barbara Bedding. *Timber in Construction*, London: BT Batsford Limited, 1985.
[7] 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.

refer to volume 3. The predicted consumption for the Drawn Study is summarised in the following table:

Function	Consumption ($l.p^{-1}.d^{-1}$)
Drinking and cooking	6.5
Personal hygiene (washing)	5
Personal hygiene (shower)	20
Laundry	5
Dish washing	1.8
Total	38.3

Predicted water consumption of the dwelling

The most significant reduction from the consumption of a typical dwelling was achieved by specifying a composting toilet; this reduces the value by 51 $l.p^{-1}.d^{-1}$, which accounts for almost one third of the consumption in a typical dwelling. Composting toilets are a proven technology, and research has rated them with as 'acceptable' to the general public as a method of reducing water consumption.[8] The only additional space requirement would be for the composting unit, occupying a volume of 2 m^3. This would be constructed from concrete block, and located in the basement.[9]

The total consumption for the dwelling would depend on the number of inhabitants; this could be based upon two design occupancy values, as the second floor is proposed as a flexible space that could be used as a workspace. In terms of the Space Standards: Area benchmark, the dwelling is based on six inhabitants. If the second floor were to be utilised as a workspace, the occupancy of the dwelling would be four, and therefore the total consumption for the dwelling would be 153.2 litres per day. If the dwelling were inhabited to its maximum predicted occupancy the predicted water consumption would be 229.8 litres per day. Taking the view that assumptions cannot be made that the space would always be used for home working, the rational conclusion would be to use the value based on the maximum designed occupancy.

[8] Griggs, J. C., M. C. Shouler and J. Hall. 'Water Conservation and the Built Environment,' in Roaf, Dr Susan and Vivien Walker (eds). *21AD : Water*, Oxford Brookes University, 1997.

The intention was to only use potable water for drinking and cooking, and that all sources of water use other than human consumption would be supplied by rainwater collected from the roof of the dwelling and stored within the basement. However, the analysis both by the assessment tool and manual calculation established that the area of the roof might be insufficient. The area of collecting surfaces required to fulfil the demand with rainwater can be determined using the following equation:[10]

$$\text{Area } (m^2) = (x \,.\, n \,.\, 365.25) / (r \,.\, 0.66)$$

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 155.3 m^2; the roof area of the Drawn Study dwelling was 55.1 m^2. The analysis established that the roof area of the dwelling as designed would guarantee only 12.9 $l.p^{-1}.d^{-1}$ and therefore the remaining 25.4 $l.p^{-1}.d^{-1}$ would have to be provided by the mains supply. In practice it might transpire that the storage capacity is sufficient to overcome the deficit arising from the low area of collecting surfaces; however this could not be ensured, as it would be dependent on a study of rainfall patterns, which ideally would be light, with a short duration and occurring at frequent periods.

Embodied Energy and Thermal Capacity

The addition of a basement to accommodate the water storage and WC composter increased the embodied energy of the dwelling over the Ecological Weight: Embodied Energy and consequent Ecological Weight: CO_2 Emission benchmarks. The thermal mass of the dwelling is very low. For the comfort of the inhabitants and efficient utilisation of internal gains the mass, and therefore embodied energy, may need to be increased.

The evaluation of the dwelling by the assessment tool established an Ecological Weight: Embodied Energy benchmark of 306.0 $kWh.m^{-2}$; this was above the benchmark of the 'urban house in paradise', of 250 $kWh.m^{-2}$. Another evaluation of the embodied energy of the dwelling was made that excluded the basement; this was not originally intended as a

[9] Personal communication with Nick Grant of Elemental Solutions, 17 October 2000.

part of the dwelling, and was only included to accommodate water storage. Furthermore, by necessity it would be formed using masonry construction, which the Study sought to avoid the use of, specifically because of its high embodied energy. Excluding the basement, and using a shallower block wall to stand the timber frame upon, reduced the benchmark to just under the target value, at 249.8 $kWh.m^{-2}$. Therefore, the inclusion of a basement to accommodate the water storage meant that the embodied energy benchmark could not be achieved. If the basement were excluded, then the embodied energy benchmark would be met. The embodied CO_2 emissions of these two variants were also calculated; they were 107.1 $kgCO_2.m^{-2}$ with the basement, and 89.9 $kgCO_2.m^{-2}$ without.

The pursuit of the Ecological Weight: Embodied Energy benchmark had a significant influence on the decision to use timber frame as the construction technology for the dwelling. However, the use of a thermally 'lightweight' structure could have disadvantages. Whilst the structure would be 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 would also be quick to cool down, as no heat would be stored in the fabric. This could be seen as an advantage in an intermittently occupied dwelling, which one in a city centre is likely to be. However, in a dwelling designed to maximise heat from solar gains, and one with very little fabric heat loss, so that intermittent gains from appliances and occupants become significant, this could lead to overheating. In a low-mass dwelling there would be little thermal capacity to absorb the excess heat. The comfort of the dwelling's inhabitants is a critical factor, as it could play a significant role in the life span of the dwelling. In a high-mass dwelling, with concrete slab ground floor, concrete beam and block upper floors, and an internal structure of dense concrete, the mass would 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 would 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"[11]

The analysis of Drawn Study 8 to determine the Ecological Weight: Embodied Energy benchmark by hand was used to calculate the thermal capacity of the dwelling. The thermal

[10] Derived from Vale, Brenda and Robert. *The Autonomous House – Design and Planning for Self-Sufficiency*, Thames and Hudson, London, 1975.
[11] Szokolay, S. *Environmental Science Handbook*, London: The Construction Press, 1980.

capacity of other construction technologies was then determined for the same design, and the tool used to establish how these perform against the Ecological Weight: Embodied Energy benchmark.[12] The total volume of the materials on the warm side on the insulation was derived from table used for the manual calculation of the embodied energy of the dwelling, contained within the following section. This included 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 was used to calculate the mass; the specific heat capacity of each material[13] was then be used to calculate their heat capacity, and these values summed results in the total heat capacity of the dwelling. This analysis is summarised in the following table.

Material	Volume (m3)	Density (kg.m-3)	Mass (kg)	Specific Heat Capacity (J.kg-1.K-1)	Heat Capacity of Dwelling (MJ.k-1)
Timber	10.64	700	7,448.8	1,700	12.6629
Plasterboard	4.19	950	3,982.0	840	3.3449
Plaster	1.05	1,120	1,173.6	1000	1.1736
Glass	0.17	2,500	414.6	837	0.3470
Total			**13,019**		**17.53**

Heat capacity of Drawn Study Seven

The total of 17.53 $MJ.K^{-1}$ was 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. This was based upon 150 mm pre cast concrete walls, with beam and block ground and internal floors. The walls would be finished in 12 mm plaster and the floor in 12 mm quarry tiles. This analysis is summarised in the following table.

[12] This calculation methodology is adopted from that used by Vale and Vale in Vale, Brenda and Robert. *The New Autonomous House - Design And Planning For Sustainability*, London: Thames & Hudson Limited, 2000.

Material	Volume (m3)	Density (kg.m-3)	Mass (kg)	Specific Heat Capacity (J.kg-1.K-1)	Heat Capacity of Dwelling (MJ.k-1)
Concrete	57.30	2,100	120,323.5	840	101.0717
Plaster	3.17	1,120	3,553.6	1,000	3.5536
Plasterboard	1.66	950	1,579.0	840	1.3264
Tiles	1.44	1,900	2,739.4	800	2.1915
Timber	0.47	700	325.6	1,700	0.5535
Glass	0.17	2,500	414.6	837	0.3470
Total			**128,935.7**		**109.04**

Heat capacity of high-mass variant of Drawn Study 7

The total of 109.04 $MJ.K^{-1}$ was also translated into a value per unit floor area of 0.879 $MJ.K^{-1}.m^{-2}$, or 0.879 $kWh.K^{-1}.m^{-2}$. 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. This would be timber frame construction, with a beam and block ground floor; the first and second floors would be constructed from timber joists over which a thin pre cast concrete slab with quarry tile finish would be laid. This would provide thermal mass to each floor, and therefore a surface for incidental gains, including solar, to be absorbed into. The analysis of the mid-mass variant is summarised in the table below.

Material	Volume (m3)	Density (kg.m-3)	Mass (kg)	Specific Heat Capacity (J.kg-1.K-1)	Heat Capacity of Dwelling (MJ.k-1)
Concrete	12.99	2,100	27,283.2	840	22.9179
Plaster	1.05	1,120	1,173.6	1,000	1.1736
Plasterboard	4.19	950	3,982.6	840	3.3454
Tiles	1.52	1,900	2,880.3	800	2.3042
Timber	5.66	700	3,964.1	1,700	6.7390
Glass	0.17	2,500	414.6	837	0.3470
Total			**39,698.4**		**36.83**

Heat capacity of mid-mass variant of Drawn Study 7

[13] 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.

The total of 36.83 $MJ.K^{-1}$ was translated into a value per unit floor area of 0.297 $MJ.K^{-1}.m^{-2}$, or 0.083 $kWh.K^{-1}.m^{-2}$.

The assessment tool was then used to determine the embodied energy values for each of these three variants; the low-mass was as the dwelling was originally designed. All other parameters in the embodied energy analysis were kept constant with the Drawn Study. The composite table below shows the thermal capacity per unit floor area and embodied energy per unit floor area of each variant.

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

Heat capacity and embodied energy of low-, mid- and high-mass variants

The thermal mass of the mid-mass variant was 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 was over six times that of the low-mass, however, the level of embodied energy had only doubled. This brief analysis suggests that the thermal mass increases at a faster rate than the increase in embodied energy.

Sustainability of Materials

The virtually exclusive use of timber and cellulose fibre insulation has meant that the dwelling would be constructed from reused, recycled and renewable materials. Therefore the dwelling would achieve all of the benchmarks that assess the sustainability of the building materials.

The use of timber frame as a construction technology has other benefits in terms of the sustainability of the materials from which the dwelling is constructed. Although without more detailed specification, which has not been feasible within the scope of this Study, it cannot be ensured that 25 percent of the 26.2 tonnes of timber used within the dwelling could be from recycled sources, any that was not would be a renewable resource. As Warmcel insulation is made from recycled newspaper, the dwelling fulfils the requirement that all insulation material would be from recycled sources. It was also proposed that the roof would be tiled in reused slates, ideally from the site itself. Therefore excluding the basement virtually all of the material used in the construction of the dwelling would be from reused, recycled or renewable sources. The in-situ concrete slab of the basement, if included, would also use recycled aggregates. Therefore in combination, the dwelling achieves the benchmarks of Use of Recycled Materials and Use of Renewable Materials, and also would meet the requirements of the benchmark that assesses the other ecological impacts of materials. The use of natural, as opposed to man-made, timber throughout the interior of the dwelling also means that it would meet the benchmark of indoor pollution, as it is free of the use of medium density fibreboard (MDF), particleboard, chipboard, formaldehyde, lead based paints, preservative treated timber and urea- formaldehyde foam insulation. Furthermore, as Warmcel is a fibre, and not foam, insulation it will achieve the benchmark requirement for Other Greenhouse Gas Emissions.

The performance of the Drawn Study in terms of the criteria of the 'urban house in paradise' can be seen in the table overleaf. The subsequent pages show the evaluation of the dwelling using the 'urban house in paradise' assessment tool.

Criteria		Benchmarks
		Ancoats: Technology of the Dwelling
CO2 emissions: Inhabitation: kgCO2.m-2.a-1		13.8 gross, -1.36 net
CO2 emissions: On Site Construction Processes: kgCO2.m-2		16.1 with basement, 13.5 without
Carbon intensity: kg.kWh-1		0.31 gross , 0 net
Construction period: weeks per dwelling		Assessed in Drawn Study 7
Contextual significance of site: Qualitative		Assessed in Drawn Study 6
Deconstruction and demolition: Recycling materials: Percent		85
Design life span: Years		Assessed in Drawn Study 7
Density:	quantitative: p.ha-1	Assessed in Drawn Study 6
	qualitative	Assessed in Drawn Study 6
Diveristy: programmes.ha-1		Assessed in Drawn Study 6
Domestic waste:	refuse: kg.p-1.wk-1	Assessed in Drawn Study 7
	recycled: kg.p-1.wk-1	Assessed in Drawn Study 7
Ecological significance of the site: Percent and qualitative		Assessed in Drawn Study 6
Ecological weight: embodied energy: kWh.m-2		306.0 with basement, 249.8 without
Ecological weight: CO2 emissions: kgCO2.m-2		107.1 with basement, 87.4 without
Energy consumption: construction: kWh.m-2		46.0 with basement, 37.5 without
Energy consumption: inhabitation: kWh.m-2.a-1		24.26
Energy generation: kWh.m-2.a-1		25.0
Green space: Percent		Assessed in Drawn Study 6
Lifecycle cost:	Construction: £.m-2.a-1	Assessed in Drawn Study 7
	Energy: £.m-2.a-1	Assessed in Drawn Study 7
	Water: £.p-1.a-1	Assessed in Drawn Study 7
Nitrogen oxide emissions: mg.kWh-1		0.0
Other ecological impacts of materials: Qualitative, g.kWh-1		A
Other greenhouse gas emissions: g.kg-1		0
Pollution: energy consumption inhabitation: g.kWh-1		5.945 gross , -0.748 net
Procurement strategy: Qualitative		Performance spec
Quality of internal environment:	indoor pollution: Qualitative	Assessed in Drawn Study 7
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 7
	ventilation: ac.h-1	Assessed in Drawn Study 7
	airtightness: ac.h-1 at 50 Pa	Assessed in Drawn Study 7
Recycling construction waste: Percent		Not Assessed
Adaptability: Internal loadbearing walls: Internal walls		Assessed in Drawn Study 7
Space standards: Area	1 person: m2.p-1	Not Applicable
	2 persons: m2.p-1	Not Applicable
	3 persons: m2.p-1	Not Applicable
	4 persons: m2.p-1	Not Applicable
	5 persons: m2.p-1	Assessed in Drawn Study 7
	6 persons: m2.p-1	Assessed in Drawn Study 7
	7 persons: m2.p-1	Not Applicable
	8 persons: m2.p-1	Not Applicable
	9 persons: m2.p-1	Not Applicable
	10 persons: m2.p-1	Not Applicable
Space standards: Volume	1 person: m3.p-1	Not Applicable
	2 persons: m3.p-1	Not Applicable
	3 persons: m3.p-1	Not Applicable
	4 persons: m3.p-1	Not Applicable
	5 persons: m3.p-1	Assessed in Drawn Study 7
	6 persons: m3.p-1	Assessed in Drawn Study 7
	7 persons: m3.p-1	Not Applicable
	8 persons: m3.p-1	Not Applicable
	9 persons: m3.p-1	Not Applicable
	10 persons: m3.p-1	Not Applicable
Thermal Performance:	Roof: W.m-2.K-1	Assessed in Drawn Study 7
	Exposed walls: W.m-2.K-1	Assessed in Drawn Study 7
	Ground and exposed floors: W.m-2.K-1	Assessed in Drawn Study 7
	Windows and rooflights: W.m-2.K-1	Assessed in Drawn Study 7
	Opaque outer doors: W.m-2.K-1	Assessed in Drawn Study 7
Use of recycled materials: Percent		Assessed in Drawn Study 7
Use of renewable raw materials: Percent		Assessed in Drawn Study 7
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l.m-2		11.91 with basement, 3.83 without
Water consumption: Inhabitation:	potable: l.p-1.d-1	Assessed in Drawn Study 7
	rain and grey: l.p-1.d-1	Assessed in Drawn Study 7
	total: l.p-1.d-1	Assessed in Drawn Study 7

Benchmark performance of Drawn Study 8

Drawn Study Eight

The benchmark target of embodied energy had significant implications on the construction technology proposed for the dwelling. A 'lightweight' dual leaf timber frame wall would be clad externally in timber boarding and insulated with cellulose fibre.

Validating the benchmark of Ecological Weight: Embodied Energy had significant implications on the choice of construction technology for the dwelling. Experience suggested that a benchmark of 250 $kWh.m^{-2}$ would require a 'lightweight' construction method. On this basis, the technology that was explored during this Study was timber frame. During the analysis of a thermal mass benchmark for the dwelling, the Study also evaluated the impact of different construction technologies on the overall embodied energy benchmark.

Traditional timber frame wall construction in the United Kingdom is typically restricted to the inner leaf. To conform to the demands of conventional appearance, most house builders use an outer leaf of brick or rendered concrete block; this was not considered appropriate, especially brick, due to the embodied energy target benchmark. Therefore a dual leaf of timber frame was proposed; this had the additional advantage that timber has a low value of thermal conductivity, of 0.14 $W.m^{-1}.K^{-1}$ as opposed to that of brick of 1.21 $W.m^{-1}.K^{-1}$. Furthermore, insulation could be in-filled between the studs, which, in relative terms, would create a high thermal performance in respect to the thickness of the element.

The dual leaf walls would have studs at 600 mm centres; these would be staggered between the panels to reduce the width of timber, and therefore increase that of the insulation, at any point in the wall. Each panel and the 100 mm cavity between them would be filled with Warmcel's 'Fibretherm K' cellulose fibre insulation. To reflect the structure of the dwelling, the external cladding of the wall panels would be timber shiplap boarding. Vertical battens would be fixed to the studs in the outer leaf, between which would be the plywood sheathing and breather membrane.

The wall panel would be constructed as a single sandwich element with both leaves and the cavity pre-filled with insulation, which would also have the external cladding fitted to the outside leaf, and brought to site as one element. The largest panel would be 8.1 metres wide and a single storey high. The windows and services within the walls, such as electrical sockets and light switches, could also be prefabricated into the panels. This strategy would be beneficial both in terms of reducing transportation and the construction period.

The highest standard that could be determined was specified for windows and doors. Within the United Kingdom the best performance that could be established was a Swedhouse UK window, triple glazed with low emissivity coatings and krypton gas fill, with a U-value of 0.95 $W.m^{-2}.K^{-1}$. Quadruple glazed Canadian windows, with low emissivity coatings, krypton gas fill and insulated spacers, have a performance of 0.73 $W.m^{-2}.K^{-1}$, but would have more embodied energy as they are manufactured outside the United Kingdom. The Ekstrands Ekodoor has a U-value of 0.55 $W.m^{-2}.K^{-1}$.

Air Tightness

The strategy to achieve the air tightness benchmark was based upon precedent. An air membrane would line each element of the dwelling's envelope, which would be carefully sealed at the junctions between elements. Details for sealing openings within the envelope were also proposed.

The principle strategy for achieving the target of air tightness would be a 'Monarflex Multifilament 250' air membrane that would line the internal face of the roof, walls and ground floor on the warm side of the insulation. In the roof the membrane would be behind the inner layer of plywood sheathing. The air membrane must be continuous throughout the dwelling. The membrane in the wall would line the inner face of the internal leaf; at the top of the wall the barrier would be brought over the top of plasterboard. Where the roof and wall meet the two membranes would be taped and sealed together using Monobond tape, and fixed back behind a plaster stop bead. The layer of plaster skimmed over the top would provide an additional airtight layer. A similar strategy would be used at the junctions between external and party walls, and walls and the ground floor.

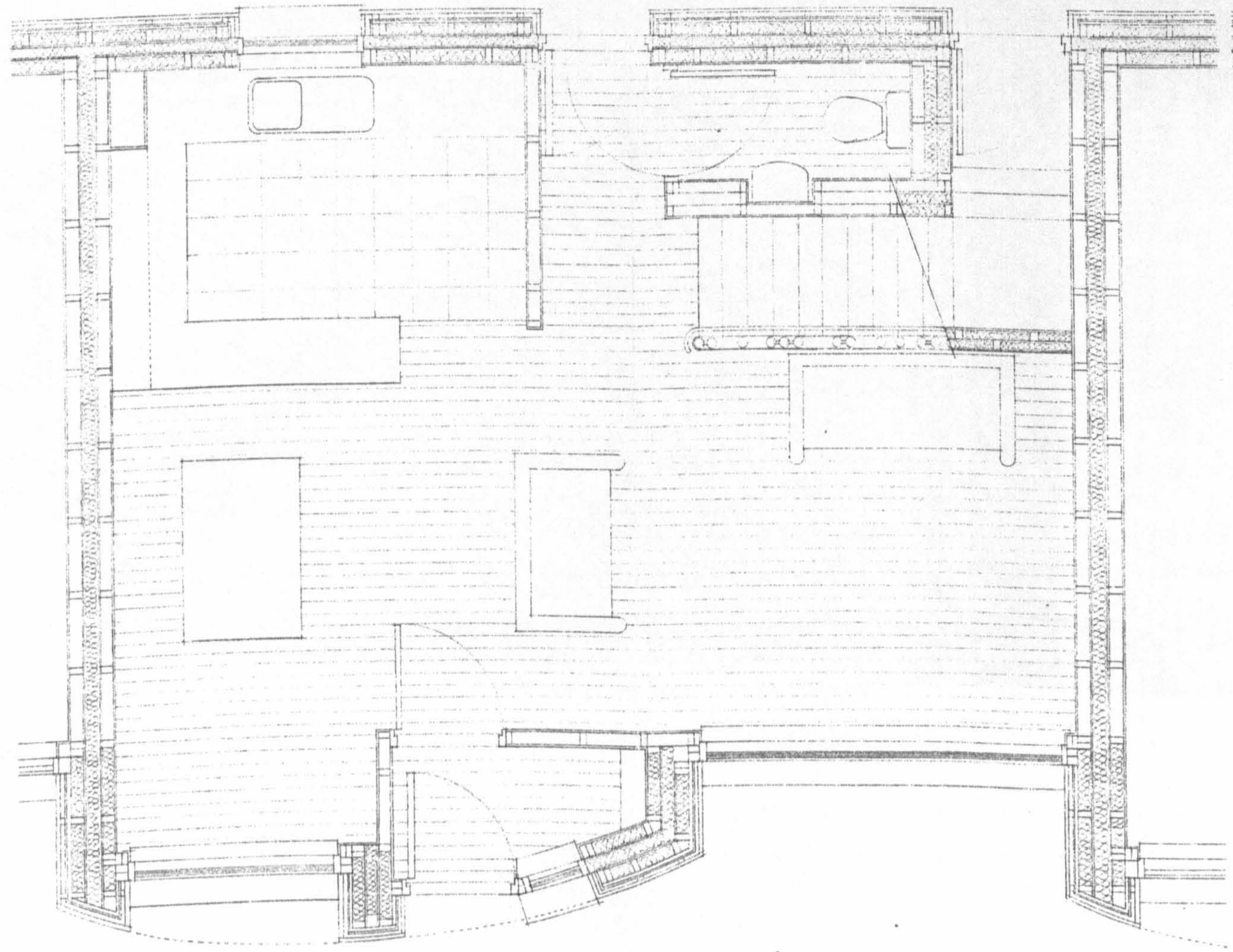
The openings for windows and doors would be other potential sources of infiltration. A plywood surround would trim the opening, to which the membrane would be taped and sealed; a silicone sealant between the plywood and the interior of the wall would ensure that the openings are sealed into the external envelope. Non-CFC foam sprayed between the back of the window frame and the plywood surround would ensure that the element is sealed into the opening. As the windows and doors themselves are constructed to a very high performance standard, where panes can be opened they have a high quality in-built seal to minimise air leakage when they are closed.

Energy Consumption and Ventilation

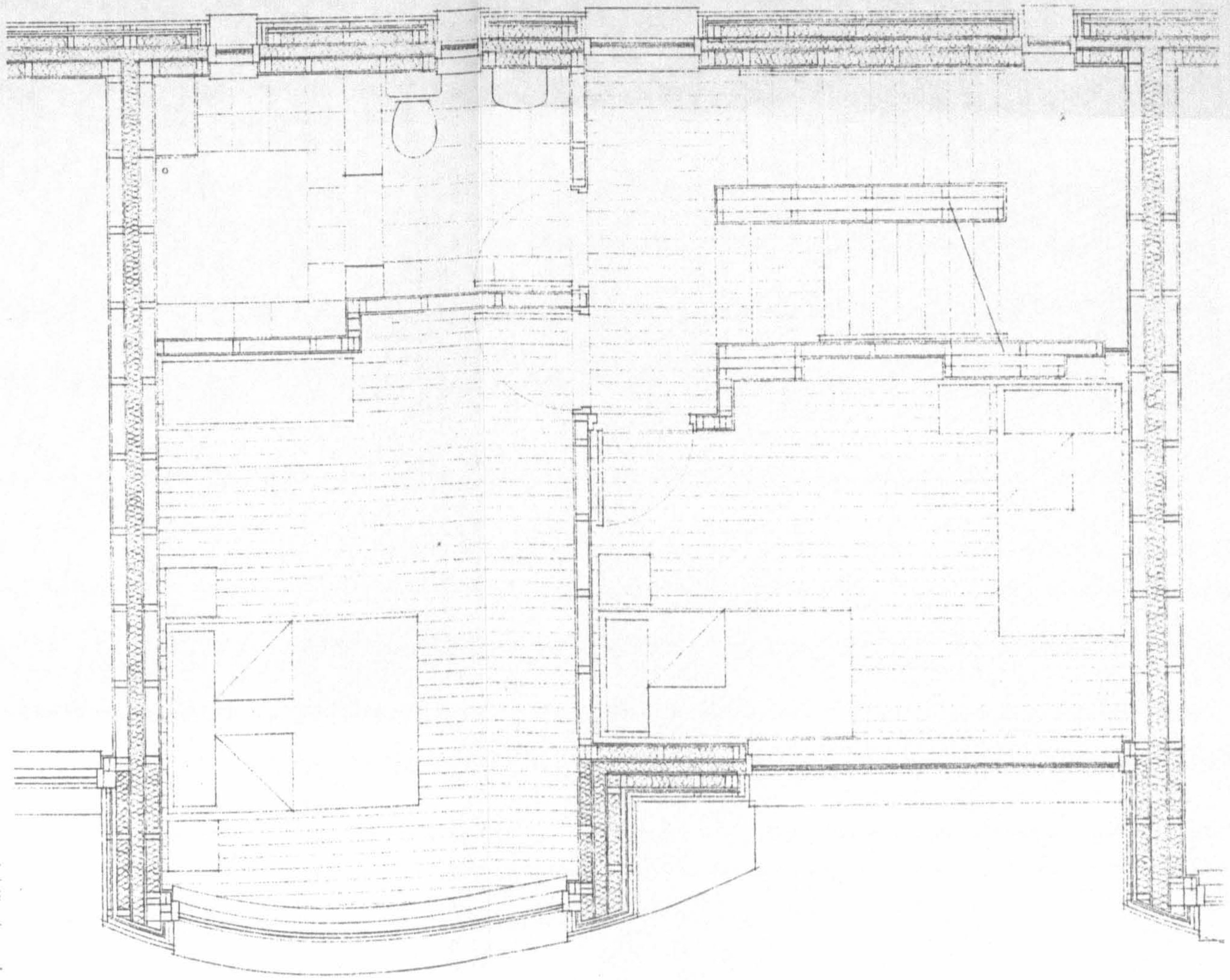
The Energy Consumption benchmark had implications on the choice of heating system that was specified for the dwelling. The very high standard of air tightness demanded a strategy for adequately ventilating the dwelling. These two demands were reconciled by a Genvex 'Combi' unit, providing warm air mechanical ventilation with heat recovery.

The energy consumption for space and water heating would be 10.2 $kWh.m^{-2}.a^{-1}$. An efficient scenario for the consumption of lights and appliances, the former of which would be achieved through the use of compact florescent light fittings, would mean that the Energy Consumption: Inhabitation benchmark would be 24.3 $kWh.m^{-2}.a^{-1}$.

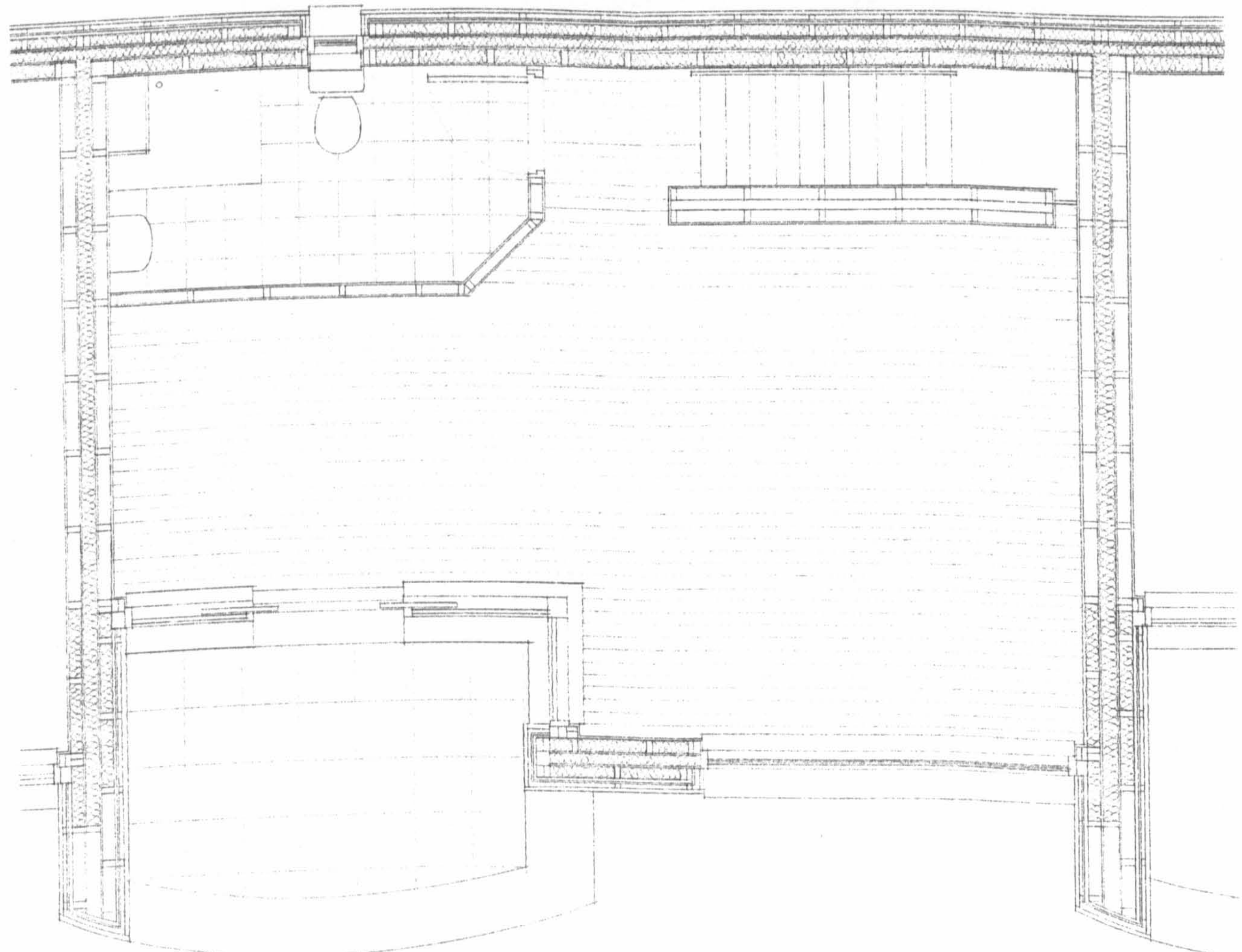
With a very high standard of air tightness, a strategy of ventilating the dwelling that would ensure an adequate supply of fresh air is required. It was proposed that, rather than using two independent systems for heating and ventilation, the Genvex warm air mechanical ventilation system with heat recovery would be appropriate. The Genvex 'Combi' unit, which has an integral hot water supply, would be located within an accessible void over a horizontal ceiling in the en-suite WC on the second floor, but within the insulated envelope.



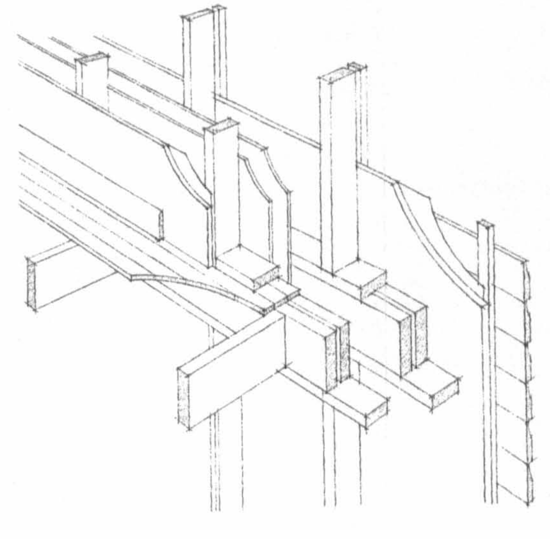
Ground floor, 1:20



First floor, 1:20



Second floor, 1:20



Perspective of external wall construction

Design Life Span

The life span was a design target benchmark. Whilst careful detailing should ensure that the timber frame would achieve the benchmark, the external cladding would have to be replaced. The life span of this is established as 30 years, and the replacement over the life span of the dwelling incorporated into the embodied energy calculations.

The decision to use timber frame construction raised the issue of the life expectancy of the structure. Under the British Standards any timber frame dwelling would be required to achieve a design life expectancy of 60 years. The Timber Research and Development Association consider that under the correct conditions, achieving a life span of 120 years would not present difficulties. The critical factor would be quality of detailing in two particular areas; firstly, around junctions and openings to ensure that moisture would be shed from the fabric and does not collect; secondly, a cavity should be provided between the external skin and the breather membrane that would allow moisture to escape or evaporate. The vertical battens to which the external boarding is fixed would create this.

It was accepted that the external boarding would not last for the design life span; it would essentially be a sacrificial layer. The specification would be for a naturally durable species that is grown in the United Kingdom. Douglas Fir is classed as 'moderately durable', with a predicted life span of 10 to 15 years. It was noted that timber used externally and not in contact with the ground, even if untreated, would have a longer life span. It was assumed that as the cladding fulfils these latter criteria, and as it would be treated, the life expectancy could be extended to 30 years. This value is borne out by the Royal Institution of Chartered Surveyors' *Life Expectancies of Building Components*, therefore 30 years was taken as a benchmark. This life span was used to account for replacement during the life span of the dwelling in the embodied energy analysis.

Drawn Study Eight

Timber I-section 'rafters' would form the asymmetric roof profile and enable the roof void to be included within the inhabited volume of the dwelling. A basement was included for water storage, a consequence of the benchmark of Water Consumption: Inhabitation.

The internal faces of the basement, including the party wall, would be constructed from Thermalite blocks; these provide the base upon which to stand the timber frame external walls. The floor would be an in-situ concrete slab; as the ground conditions are unknown, a basic strip foundation beneath the block walls was assumed. The external face of the basement walls would be tanked and protected by a layer of hardboard; backfill of broken brick from the demolition of the existing buildings on site would ensure good drainage. To some extent the inclusion of the basement was justified, as the clearance of the site and probable remediation would require a degree of excavation, although not as extensive. The timber ground floor would be underlined with plywood, fixed back to the joists. Warmcel insulation would then be laid between the joists before timber floorboards are laid across.

To create the depth of roof structure to accommodate 600 mm of insulation timber I-section beams were proposed, constructed with a plywood web and softwood flanges. Timber noggins would give these lateral bracing, and prevent the insulation sinking to the eaves. Plywood panels would sheathe either side of the I-sections to contain the insulation. Timber battens create a cavity between the internal face of plywood and fireboard, within which wiring would run. Therefore the air membrane, which would be behind the plywood sheathing, does not have to be pierced by services. The outside face of the roof would be tiled from existing buildings on the site. The photovoltaic array would be integrated into the roof. The sub-frame for the array would be carried on the horizontal roof battens; the frame runs up the roof pitch, creating an air cavity behind the panels to ventilate them.

Water Consumption

The predicted water consumption achieved the overall benchmark. However, despite the inclusion of adequate storage in a basement, the roof proved insufficient to provide the area of collection surfaces required for harvesting rainwater.

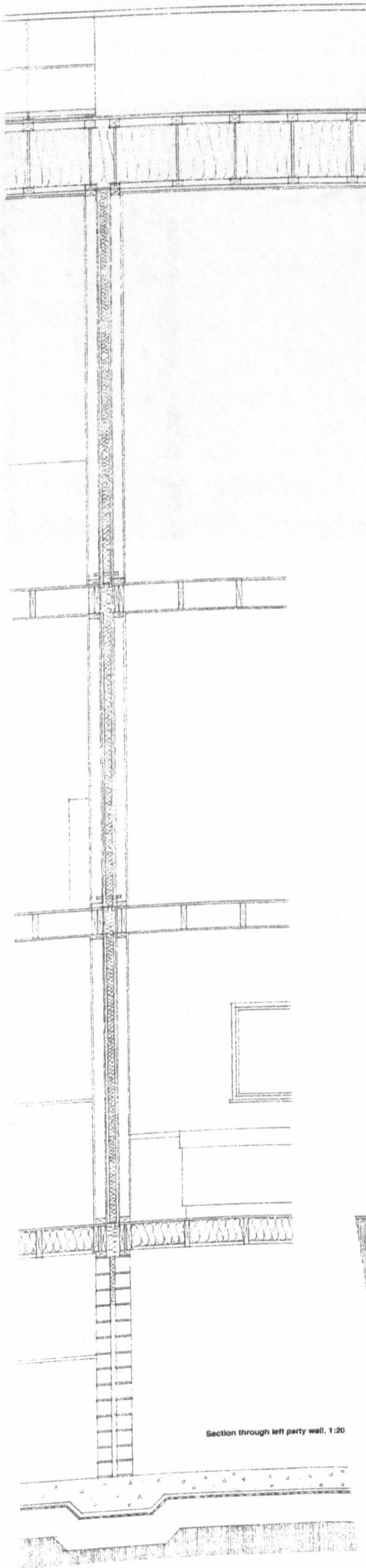
The water consumption benchmark was determined as 38.3 $l.p^{-1}.d^{-1}$. The most significant reduction from the consumption of a typical dwelling was achieved by specifying a composting toilet. The only additional space requirement would be for the composting unit, occupying a volume of 2 m^3. This would be constructed from concrete block, and located in the basement. If the dwelling were inhabited to its maximum designed occupancy the predicted water consumption would be 229.8 litres per day. The intention was to only use potable water for drinking and cooking and that all sources of water use other than human consumption would be supplied by rainwater collected from the roof and stored within the basement. However, analysis established that the roof area of the dwelling as designed would guarantee only 12.9 $l.p^{-1}.d^{-1}$ and therefore the remaining 25.4 $l.p^{-1}.d^{-1}$ would have to be provided by the mains supply. In practice it might transpire that the storage capacity is sufficient to overcome the deficit; however this could not be ensured, as it would be dependent on a study of rainfall patterns, which ideally would be light, with a short duration and occurring at frequent periods.

Embodied Energy and Thermal Capacity

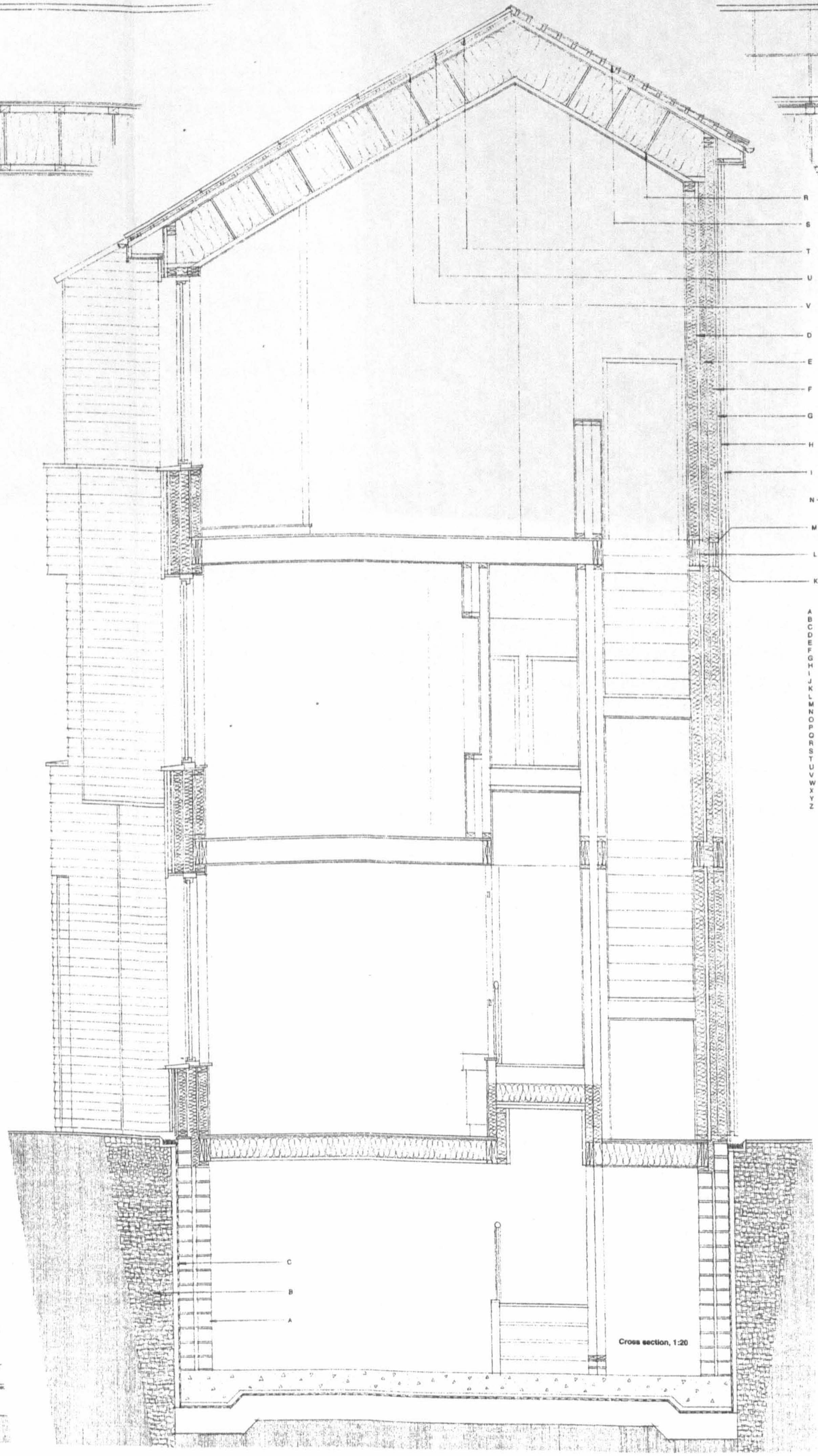
The addition of a basement increased the embodied energy of the dwelling over the Ecological Weight: Embodied Energy and Ecological Weight: CO_2 Emission benchmarks. For the comfort of the inhabitants and efficient utilisation of internal gains the thermal mass, and therefore embodied energy, may need to be increased.

The Ecological Weight: Embodied Energy benchmark was calculated as 306.0 $kWh.m^{-2}$. Another evaluation was made that excluded the basement, of 249.8 $kWh.m^{-2}$. Therefore, the inclusion of a basement meant that the embodied energy benchmark could not be achieved. The embodied CO_2 emissions of these two variants were 107.1 $kgCO_2.m^{-2}$ with the basement, and 89.9 $kgCO_2.m^{-2}$ without. The pursuit of the Ecological Weight: Embodied Energy benchmark had a significant influence on the use a thermally 'lightweight' structure; however this could have disadvantages. Whilst the structure would be quick to warm up, as the vast majority of the input by the heating system will go into warming the internal space of the dwelling, it would also be quick to cool down, as no heat is stored in the fabric. In a dwelling designed to maximise heat from solar gains this could lead to overheating; in a low-mass dwelling there would be little thermal capacity to absorb the excess heat. In a high-mass dwelling the fabric can absorb and store incidental gains, and release them over a period of time maintaining the internal temperature at a steady level.

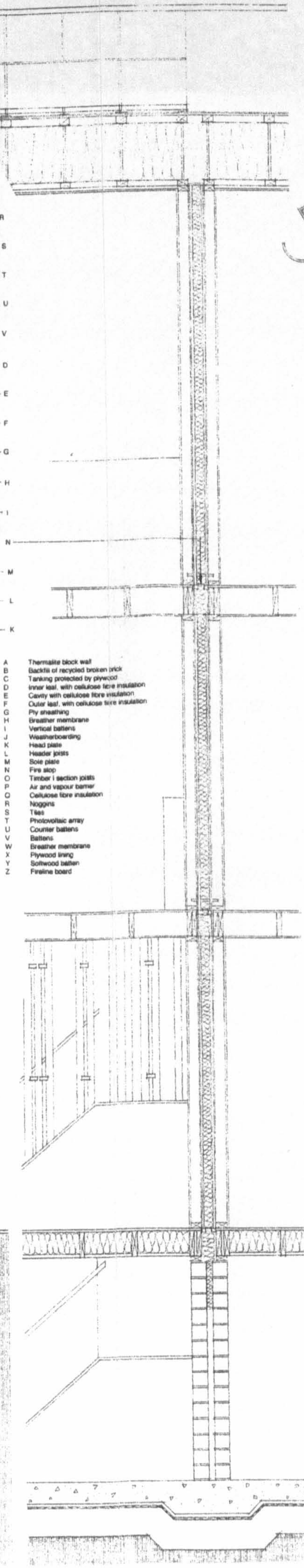
The thermal capacity of the dwelling was also calculated. From the total volume of each material on the warm side on the insulation, the density was used to calculate their mass; the specific heat capacity was then used to calculate their individual heat capacity, and these values summed to establish the total heat capacity of the dwelling. The total of 17.53 $MJ.K^{-1}$ was translated into a value per unit floor area of 0.036 $kWh.K^{-1}.m^{-2}$. A high thermal mass variant for the Drawn Study was also explored. The thermal mass was 0.879 $kWh.K^{-1}.m^{-2}$. From these two scenarios, it can be seen that the high-mass variant would have 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 thermal mass was 0.063 $kWh.K^{-1}.m^{-2}$. The embodied energy for each of these three variants was also determined. These were 306.0, 369.6 and 576.7 $kWh.m^{-2}$ for the low-, mid- and high- mass variants respectively. The thermal mass of the mid-mass variant was 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 was over six times that of the low-mass, however, the level of embodied energy had only doubled.



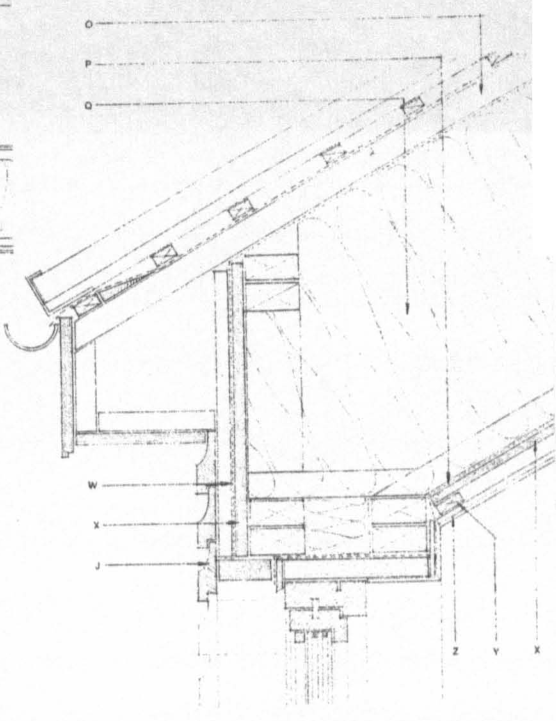
Section through left party wall, 1:20



Cross section, 1:20



A	Thermalite block wall
B	Backfill of recycled broken brick
C	Tanking protected by plywood
D	Inner leaf, with cellulose fibre insulation
E	Cavity with cellulose fibre insulation
F	Outer leaf, with cellulose fibre insulation
G	Ply sheathing
H	Breather membrane
I	Vertical battens
J	Weatherboarding
K	Head plate
L	Header joists
M	Sole plate
N	Fire stop
O	Timber I section joists
P	Air and vapour barrier
Q	Cellulose fibre insulation
R	Noggins
S	Tiles
T	Photovoltaic array
U	Counter battens
V	Battens
W	Breather membrane
X	Plywood lining
Y	Softwood batten
Z	Fireline board



Detail of eaves at window head, 1:5

Sustainability of Materials

The virtually exclusive use of timber and cellulose fibre insulation has meant that the dwelling would be constructed from reused, recycled and renewable materials.

Although without more detailed specification it cannot be ensured that 25 percent of the 26.2 tonnes of timber used within the dwelling could be derived from recycled sources, any that was not would be a renewable resource. As Warmcel insulation is made from recycled newspaper, the dwelling fulfils the requirement that all insulation material would be from recycled sources. It was also proposed that the roof would be tiled in reused slates, ideally from the site itself. Therefore excluding the basement virtually all of the materials used in the construction of the dwelling would be from reused, recycled or renewable sources. The in-situ concrete slab of the basement, if included, would also use recycled aggregates. The use of natural, as opposed to man-made, timber throughout the interior of the dwelling also means that it would meet the benchmark of indoor pollution. Furthermore, as Warmcel is a fibre, and not foam, insulation it will achieve the benchmark requirement for Other Greenhouse Gas Emissions.

Criteria		Benchmarks Analysis: Technology of the Dwelling
CO2 emissions: Inhabitation kgCO2.m-2.a-1		13.8 gross, -1.38 net
CO2 emissions: On Site Construction Processes kgCO2.m-2		16.1 with basement, 13.5 without
Carbon intensity kg kWh-1		0.31 gross, 0 net
Construction period: weeks per dwelling		Assessed in Drawn Study 7
Contextual significance of site: Qualitative		Assessed in Drawn Study 6
Deconstruction and demolition: Recycling materials Percent		88
Design life span: Years		Assessed in Drawn Study 7
Density	quantitative: p ha-1	Assessed in Drawn Study 6
	qualitative	Assessed in Drawn Study 6
Diversity: programmes.ha-1		Assessed in Drawn Study 6
Domestic waste	in use: kg p-1 wk-1	Assessed in Drawn Study 7
	recycled: kg p-1 wk-1	Assessed in Drawn Study 7
Ecological significance of the site: Percent and qualitative		Assessed in Drawn Study 6
Ecological weight: embodied energy: kWh m-2		306.0 with basement, 249.8 without
Ecological weight: CO2 emissions: kgCO2 m-2		107.1 with basement, 89.9 without
Energy consumption: construction: kWh m-2		49.0 with basement, 37.5 without
Energy consumption: inhabitation: kWh m-2 a-1		24.20
Energy generation: kWh m-2 a-1		55.0
Green space: Percent		Assessed in Drawn Study 6
Lifecycle cost	Construction: £ m-2 a-1	Assessed in Drawn Study 7
	Energy: £ m-2 a-1	Assessed in Drawn Study 7
	Water: £ p-1 a-1	Assessed in Drawn Study 7
Nitrogen oxide emissions: mg kWh-1		0.0
Other ecological impacts of materials: Qualitative, g kWh-1		A
Other greenhouse gas emissions: g kp-1		5
Pollution, energy consumption inhabitation: g kWh-1		5.945 gross, -0.748 net
Procurement strategy: Qualitative		Performance spec
Quality of internal environment	indoor pollution: Qualitative	Assessed in Drawn Study 7
	daylight: living, kitchen, beds: Percent	Assessed in Drawn Study 7
	ventilation: ac h-1	Assessed in Drawn Study 7
	airtightness: ac h-1 @ 50 Pa	Assessed in Drawn Study 7
Recycling construction waste: Percent		Not Assessed
Adaptability: internal loadbearing walls: external walls		Assessed in Drawn Study 7
Space Standards: Area	1 person: m2 p-1	Not Applicable
	2 persons: m2 p-1	Not Applicable
	3 persons: m2 p-1	Not Applicable
	4 persons: m2 p-1	Not Applicable
	5 persons: m2 p-1	Assessed in Drawn Study 7
	6 persons: m2 p-1	Assessed in Drawn Study 7
	7 persons: m2 p-1	Not Applicable
	8 persons: m2 p-1	Not Applicable
	9 persons: m2 p-1	Not Applicable
	10 persons: m2 p-1	Not Applicable
Space Standards: Volume	1 person: m3 p-1	Not Applicable
	2 persons: m3 p-1	Not Applicable
	3 persons: m3 p-1	Not Applicable
	4 persons: m3 p-1	Not Applicable
	5 persons: m3 p-1	Assessed in Drawn Study 7
	6 persons: m3 p-1	Assessed in Drawn Study 7
	7 persons: m3 p-1	Not Applicable
	8 persons: m3 p-1	Not Applicable
	9 persons: m3 p-1	Not Applicable
	10 persons: m3 p-1	Not Applicable
Thermal Performance	Roof: W m-2 K-1	Assessed in Drawn Study 7
	Exposed walls: W m-2 K-1	Assessed in Drawn Study 7
	Ground and exposed floors: W m-2 K-1	Assessed in Drawn Study 7
	Windows and rooflights: W m-2 K-1	Assessed in Drawn Study 7
	Opaque outer doors: W m-2 K-1	Assessed in Drawn Study 7
Use of recycled materials: Percent		Assessed in Drawn Study 7
Use of renewable raw materials: Percent		Assessed in Drawn Study 7
Utilisation of local resources: km		Not Assessed
Water consumption: construction: l m-2		11.91 with basement, 3.93 without
Water consumption: inhabitation	potable: l p-1 d-1	Assessed in Drawn Study 7
	rain and grey: l p-1 d-1	Assessed in Drawn Study 7
	none: l p-1 d-1	Assessed in Drawn Study 7

drawn study 8 sheet 2 of 2

The Performance Benchmark Assessment Tool

Dimensional Information	Data		Data		Answer
Ground floor - Area (m2):	44.89	Ceiling height (m):	3	Volume (m3) =	134.67
First floor - Area (m2):	44.68	Ceiling height (m):	3	Volume (m3) =	134.04
Second floor - Area (m2):	36.86	Ceiling height (m):	4.2	Volume (m3) =	154.812
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
				Total floor area (m2) =	126.43
Number of storeys:	3			Total volume (m3) =	423.522
Dwelling perimeter (m):	29.2			Space standards: Area (m2.p-1) =	21.07166667
Building height (mean wall height) (m):	10.2			Space standards: Volume (m3.p-1) =	70.587
Designed occupancy level:	6				

Ventilation	Data			Answer
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 infiltrtration =	0.0085
			Shelter factor =	0.85
Number of sheltered sides:	2	Enter '2' if unknown		0.177225
			If mechanical ventilation: vent rate =	0.45
Mechanical ventilation? Yes=1, No=0:	1			0.007225
If no heat recovery, enter 0.33:	0		If natural ventilation, vent rate =	0.45
Natural ventilation? Yes=1, No=0:	0		Effective ventilation rate =	0.18

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):	0.6		
Sheathing material - Thickness (m):	0.03	Conductivity (W/m.K):	0.14		
Outer structure - Thickness (m):	0.6	Conductivity (W/m.K):	0.14		
Insulation - Thickness (m):	0.6	Conductivity (W/m.K):	0.035		
Inner structure - Thickness (m):	0	Conductivity (W/m.K):	1		
Inner finish - Thickness (m):	0.012	Conductivity (W/m.K):	0.46		
Rso:	0.04				
Rcav:	0				
Rsi:	0.12				
Roof pitch (degrees):	35				
Is insulation laid in plane at pitch to ceiling? Yes=1, No=0:	1				
Is insulation laid in plane parallel to ceiling? Yes=1, No=0:	0				
Is roof solid construction? Yes=1, No=0:	0				0.047404835
Is roof timber construction? Yes=1, No=0:	1	Joist centre to centre (m):	0.6		0.084765803
Joist width (m):	0.05			U-Roof =	0.08

U-Wall

Outer finish - Thickness (m):	0	Conductivity (W/m.K):	1
Outer leaf - Thickness (m):	0.02	Conductivity (W/m.K):	0.14
Sheathing material - Thickness (m):	0.03	Conductivity (W/m.K):	0.14
Insulation - Thickness (m):	0.32	Conductivity (W/m.K):	0.036
Inner structure - Thickness (m):	0.32	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				0.083978336
Is wall solid construction? Yes=1, No=0:	0				0.124094747
Is wall timber frame construction? Yes=1, No=0:	1				
If timber frame, stud width (m):	0.05	Stud centre to centre (m):	0.6	U-Wall =	0.12
U-Ground					
Is floor a non-suspended floor? Yes=1, No=0:	0	Is floor a suspended floor? Yes=1, No=0:	1		
Are only 2 parallel edges exposed?	1	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):	0.14		
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			β =	1.389736171
Deck or slab - Thickness (m):	0.019	Conductivity (W/m.K):	0.14		1
Insulation - Thickness (m):	0.22	Conductivity (W/m.K):	0.035	Corrected length =	7.9
External wall thickness (m):	0.45	Thernal conductivity of earth (W/m.K), or 1.4:	1.4	Correctedbreadth =	5.2
Floor length (greater dimension) (m):	7.9	Floor breadth (lesser dimension) (m):	5.2		
Rsi:	0.14			Unonsuspended =	0.131496012
				Ususpended=	0.095525797
				U-Ground =	0.10
U-Windows					
Independent manufacturer's U-value for glazing:	0.8			U-Window and Rooflight =	0.8
U-Doors					
Independent manufacturer's U-value for doors:	0.55			U-Door =	0.55
Heat Loss Parameters					
Roof area (excluding openings) (m2):	55.08				
External wall area (excluding openings) (m2):	129.2				
Party wall area (m2):	112.2				
Ground floor area (m2):	44.89				
Window area (m2):	37.12				
Rooflight area (m2):	0				
Door area (m2):	3.8	U-value:		Total area of dwelling envelope =	382.29
Other element, area (m2):				Ventilation heat loss =	24.76936653
				Heat loss coefficient =	81.54546127
				Heat loss parameter =	0.644985061
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:				Energy requirement =	6.737105794
Predicted hot water consumption (l.p-1.d-1) (Table O):	20.4	Temp difference between supply and heated (oC):	36	Distribution losses =	1.192467725
		36 oC if header tank is within insulated envelope, otherwise 49 oC			
On the basis of floor area:					
Hot water energy requirement (Table O1):	4.4	Distribution losses (Table O1):	0.78		
		Storage loss factor (Table E):	0.0078	Actual energy requirement =	4.4
Hot water storage volume (litres):	185	Efficiency of water heater (Table G1 or G2):	250	Actual distribution losses =	0.78
Primary circuit losses (Table F):	0.5	Value should be adjusted by amount shown in 'efficiency adjustment' column in Table G3 and G5 where appropriate.		Energy for water heating =	2.8492
				Heat gains from water heating =	3.2784
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 =	368.630137
Mean wattage of light bulbs (W), e.g. 13.5 or 80:	13.5			Lighting gains =	20.26386986

Total annual appliance consumption (kWh.a-1) (Table R)	
Total annual cooking consumption (kWh.a-1) (Table R)	
Appliance gains =	0
Cooking gains =	0
On basis of floor area:	
Lights, appliances, cooking and metabolic (W) (Table H):	715
Actual met, light, app and cook gains =	715
Additional gains (W) (Table H):	25
Water heat gains =	103.958064
Total internal incidental gains =	843.958064

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):	35	Solar flux (W.m-2):	23
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):	2.04	Solar flux (W.m-2):	12
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 =	829.48
Total gains =	1673.438064
Gains/loss ratio =	20.52153533
Useful gains =	987.3284578

For Utilisation Factor, refer to Table K

Utilisation factor:	0.59

Mean Internal Temperature

Mean internal temperature of living area (Table L):	18.88
Temperature adjustment (Table G5, if applicable):	0
Heating system responsiveness, R (Table G1 or G4):	1
Temperature difference between zones (Table M):	0.4
Living room area (m2):	13.5
Mean internal temperature =	20.14425255

Degree Days

Base temperature =	8.036546708
Degree days (Table N):	620
Useful energy requirement =	1213.396464

Water Consumption

Refer to Table O to determine predicted water consumption

Predicted consumption benchmark (litre/p/day):	38.3
Rainwater storage (litres):	30042
Storage ratio =	2.334483402
If storage ratio <1, enter value; if not, enter 1:	1
	25.94095342
Area of rainwater collection surfaces (m2):	55.08
Rainfall (mm.a-1) (Table P):	819
Potable consumption =	25.94095342
Rainwater consumption =	12.35904658

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			Primary space heating =	505.5818598
Efficiency of primary heating system (%):	240	Efficiency of secondary heating system (%):	1	Secondary space heating =	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:	0.5	Space heating from CHP =	577.8078398
Distribution Loss Factor (Table O2):	1.05	Fraction taken from operational records or design specification		Space heating from boilers =	577.8078398

				Primary space heating =	505.5818598
				Secondary space heating =	0
				Water heating =	791.4444444
Pumps and Fans consumption:					
Number of central heating pumps:	0	Number of boilers with fan assisted flues:	0	Pumps and fans =	470.5752942
Warm air heating fans? Yes=1, No=0:	0	Full mechanical ventilation? Yes=1, No=0:	1		
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 =	177.5115
Total consumption of appliances (kWh.a-1) (Table R):	0			Consumption =	0
On basis of floor area:					
Lights and appliances (Table S):	1000			Lights and appliances =	1000
Cooking consumption:					
Total Cooking (kWh.a-1) (Table T):	300			Cooking =	300
				Energy Consumption: Inhab =	24.26324131
Energy Generation					
Photovoltaic Panels					
Annual solar energy availability, (kWh.m-2.a-1) :	1040	Efficiency of panel (%), or 19%:	19		
Refer to Table U for value by location, or 1000 kWh.m-2.a-1				Generation per annum =	3161.6
Area of photovoltaic array (m2):	16				
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):		Windspeed at hub height =	#NUM!
Roughness length (m), 0.4 m for urban areas:	0.4			Generation per annum =	0
Annual energy yield:		Number of turbines:		Generation per annum =	0
Other sources (kWh per annum):				Energy Generation: Inhab =	25.00672309
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:	0.59	Pollution emission factor:	6.494	Gross CO2 emission =	13.77242768
Secondary space heating - CO2 emission factor:	0	Pollution emission factor:	0	Net CO2 emission =	-1.357396152
Water Heating - CO2 emission factor:	0.59	Pollution emission factor:	6.494	Gross Pollution Emissions - Inhab =	5.944873933
				Net Pollution Emissions - Inhab =	-0.748117233
For community systems without CHP:				Gross CO2 emission =	10.54263007
Primary space heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Net CO2 emission =	-8.588272405
Water Heating - CO2 emission factor:	0.19	Pollution emission factor:	0.879	Gross Pollution Emissions - Inhab =	3.737368727
				Net Pollution Emissions - Inhab =	-2.955622439
				CO2 emission factor for heat =	0.085
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 =	10.377873
CHP fuel - CO2 emission factor:	0.19	CHP fuel - pollution emission factor:	0.879	Net CO2 emission =	-8.753029476
Electricity CO2 emission factor:	0.59	Electricity - pollution emission factor:	6.494	Gross Pollution Emissions - Inhab =	5.254094195
Boiler - CO2 emission factor:	0.19	Boiler - pollution emission factor:	0.879	Net Pollution Emissions - Inhab =	-1.438896971

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):	72				
				Gross CO2 emission =	13.77242768
				Net CO2 emission =	-1.357396152
				Gross Pollution Emissions - Inhab =	5.944873933
				Net Pollution Emissions - Inhab =	-0.748117233
				CO2 Emmision: Inhabitation =	13.77242768
				Pollution Emissions - Inhab =	5.9449

Lifespan and Replacement Ratios

For life expectancy of building components, refer to Table X

Lifespan benchmark (years):	120			
Roof external finish - Life span (years):	60	2.00	Replacement ratio =	2
Roof structure - Life span (years):	120	1.00	Replacement ratio =	1
Roof insulation - Life span (years):	120	1.00	Replacement ratio =	1
Roof internal finish - Life span (years):	73	1.64	Replacement ratio =	2
Wall external finish - Life span (years):	30	4.00	Replacement ratio =	4
Wall structure - Life span (years):	120	1.00	Replacement ratio =	1
Wall insulation - Life span (years):	120	1.00	Replacement ratio =	1
Wall internal finish - Life span (years):	73	1.64	Replacement ratio =	2
Window and rooflight - Life span (years):	60	2.00	Replacement ratio =	2
Floor finish - Life span (years):	120	1.00	Replacement ratio =	1
Floor structure - Life span (years):	120	1.00	Replacement ratio =	1
Floor insulation - Life span (years):	120	1.00	Replacement ratio =	1
Internal Staircases - Life span (years):	78	1.54	Replacement ratio =	2
Photovoltaic panels - Life span (years):	25	4.80	Replacement ratio =	5
Solar water panels - Life span (years):	25	4.80	Replacement ratio =	5

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):	0.5	Volume =, or insert value (m3):	2.92
Strip/trench - Density (kg/m3):	2600	Strip/trench - Embodied energy (kWh/kg):	0.2		1518.40
Wall width below ground (combined if twin leaf):	0.2	Depth of wall below ground (m):	2.3	Volume =, or insert value (m3):	13.43
Wall - Density (kg/m3):	1200	Wall - Embodied energy (kWh/kg):	0.5		8059.20
Cavity width (m):	0.1	Depth of cavity fill (m):	2.3	Volume =, or insert value (m3):	6.72
Cavity fill - Density (kg/m3):	500	Cavity fill - Embodied energy (kWh/kg):	0.01		33.58
					9611.18
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 =	9611.18
Basement					
Perimeter, as ground floor or other (m2):	29.2	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):		Wall Insulation - Embodied energy (kWh/kg):		Volume =, or insert value (m3):	11.22
Area of floor, as ground floor or other (m2):	44.89	Depth of floor (m):	0.25		5835.70
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):		Floor insulation - Embodied energy (kWh/kg):		Volume =, or insert value (m3):	13.47
Hardcore depth (m):	0.3				
Note: *Enter zero if to be accounted for in ground floor analysis*					673.35
Hardcore - Density (kg/m3):	500	Hardcore - Embodied energy (kWh/kg):	0.1	Embodied Energy - Basement =	6509.05
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):	7.7	Length of span (m):	5.3		
Number of joists = actual, or:	14	Number of noggins = actual, or:	2	Volume =, or insert value (m3):	1.82
Area of noggin cross-section (m2):	0.0026				127.43
Timber - Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	9.88
Insulation					116.14
Insulation - Density (kg/m3):	24	Insulation - Embodied energy (kWh/kg):	0.49		243.57
If concrete slab:				Volume =, or insert value (m3):	2.24
Screed					1077.36
Screed - Density (kg/m3):	800	Screed - Embodied energy (kWh/kg):	0.6	Volume =, or insert value (m3):	13.47
Concrete					7002.84
Concrete - Density (kg/m3):	2600	Concrete - Embodied energy (kWh/kg):	0.2	Volume =, or insert value (m3):	9.88
Insulation					120.98
Insulation - Density (kg/m3):	25	Insulation - Embodied energy (kWh/kg):	0.49	Volume =, or insert value (m3):	13.47
Hardcore					673.35
Hardcore - Density (kg/m3):	500	Hardcore - Embodied energy (kWh/kg):	0.1		8874.53
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):	2.24
Screed depth (m):	0.05				1077.36
Screed - Density (kg/m3):	800	Screed - Embodied energy (kWh/kg):	0.6	Volume =, or insert value (m3):	9.8758
Insulation					120.97855
Insulation - Density (kg/m3):	25	Insulation - Embodied energy (kWh/kg):	0.49		1198.34
External Walls				Embodied Energy - Gnd Floor =	243.57
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):	2.58
Outer leaf - Density (kg/m3):	1750	Outer leaf - Embodied energy (kWh/kg):	1.2		5426.40
Insulation				Volume =, or insert value (m3):	41.34
Insulation - Density (kg/m3):	40	Insulation - Embodied energy (kWh/kg):	0.49		810.34
Inner leaf				Volume =, or insert value (m3):	41.34
Inner leaf - Density (kg/m3):	1200	Inner leaf - Embodied energy (kWh/kg):	0.5		24806.40
Internal finish				Volume =, or insert value (m3):	1.55
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5		930.24
				Embodied energy =	31973.38
External Walls - Timber Frame				Volume =, or insert value (m3):	0.00
External finish					0.00
External finish - Density (kg/m3):	700	External finish - Embodied energy (kWh/kg):	0.1		
Outer leaf				Volume =, or insert value (m3):	2.58
Outer leaf - Density (kg/m3):	700	Outer leaf - Embodied energy (kWh/kg):	0.1		723.52
Sheathing ply				Volume =, or insert value (m3):	3.88
Sheathing ply - Density (kg/m3):	700	Sheathing ply - Embodied energy (kWh/kg):	0.1		271.32
Insulation				Volume =, or insert value (m3):	37.90
Insulation - Density (kg/m3):	40	Insulation - Embodied energy (kWh/kg):	0.49		742.81
Stud width (m):	0.05	Stud depth (m):	0.32		
Sole plate width (m):	0.2	Sole plate depth (m):	0.05		
Head plate width (m):	0.2	Head plate depth (m):	0.05		
Header Joist width (m):	0.1	Hearder Joist depth (m):	0.25	Volume =, or insert value (m3):	8.31
Inner leaf					581.63
Inner leaf - Density (kg/m3):	700	Inner leaf - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	1.55
Internal finish					930.24
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5	Embodied energy =	3249.52
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):	40.15
Inner leaf - Thickness (m):	0.32				24068.32
Inner leaf - Density (kg/m3):	1200	Inner leaf - Embodied energy (kWh/kg):	0.5	Volume =, or insert value (m3):	1.50552
Internal finish - Thickness (m):	0.012				903.312
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5	Embodied energy =	24991.63
Party Walls - Timber Frame				Volume =, or insert value (m3):	3.7638
Sheathing ply					263.466
Sheathing ply - Density (kg/m3):	700	Sheathing ply - Embodied energy (kWh/kg):	0.1	Volume =, or insert value (m3):	5.75025
Insulation - Thickness (m):	0.05				112.7049
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):	0.2	Sole plate depth (m):	0.05		
Head plate width (m):	0.2	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):	3.63
Inner leaf - Density (kg/m3):	700	Inner leaf - Embodied energy (kWh/kg):	0.1		253.995
Internal finish - Thickness (m):	0.012			Volume =, or insert value (m3):	1.50552
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh/kg):	0.5		903.312
				Embodied energy =	1533.48
Internal Load Bearing Walls					
Length of internal loadbearing walls (m):	0	Height of internal loadbearing walls (m):	6		
Masonry					
Structure - Thickness (m):	0.32			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):	0.32		
Sole plate width (m):	0.2	Sole plate depth (m):	0.05		
Head plate width (m):	0.2	Head plate depth (m):	0.05		
Header Joist width (m):	0.1	Hearder Joist depth (m):	0.25		
Structure - Thickness (m):	0.32			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 =	4783.001767
Windows and Rooflights					
Level of glazing:	3	Pane tickness (m):	0.004	Volume =, or insert value (m3):	0.44544
Glass - Density (kg/m3):	2500	Glass - Embodied energy (kWh/kg):	6		13363.2
Perimeter of windows and rooflights, inc midrails (m):	72.4	Area of frame cross section (m2):	0.005	Volume =, or insert value (m3):	0.362
Frame - Density (kg/m3):	700	Frame - Density (kg/m3):	0.1		50.68
				Embodied Energy - Glazing =	13413.88
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):	7.7	First floor - length of span (m):	5.3		
Joist spacing (m):	0.6	Number of joists = actual, or:	14		
Joist depth (m):	0.25	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):	81.54	Volume =, or insert value (m3):	3.314998845
Timber Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1		232.0499192
Soffit finish thickness (m)	0.015			Volume =, or insert value (m3):	1.2231
Soffit finish - Density (kg/m3):	600	Soffit finish - Embodied energy (kWh/kg):	0.5		733.86
				Embodied energy =	965.9099192
If concrete beam and block:					
First floor - dimension perpendicular to span (m):	7.9	First floor - length of span (m):	5.2		
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:	156	Volume =, or insert value (m3):	18.72
					13478400
Beam - Density (kg/m3):	1200	Beam - Embodied energy (kWh/kg):	600	Volume =, or insert value (m3):	50.544
					24261120
Block - Density (kg/m3):	800	Block - Embodied energy (kWh/kg):	600	Volume =, or insert value (m3):	2.234
Screed depth (m):	0.05				1072.32
Screed - Density (kg/m3):	800	Screed - Embodied energy (kWh/kg):	0.6	Volume =, or insert value (m3):	1.2231
Soffit finish thickness (m)	0.015				733.86
Soffit finish - Density (kg/m3):	600	Soffit finish - Embodied energy (kWh/kg):	0.5	Embodied Energy =	68876470.16

Total area of internal floors (m2):	81.54			Embodied Energy - Int'l Floors =	965.9099192
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	2				
For stairs other than precast concrete					
Number of treads	16	Number of risers	17		
Tread length (m):	0.23	Tread width (m):	0.92		
Tread thickness (m):	0.025			Volume =, or insert value (m3):	0.08464
Tread - Density (kg/m3):	700	Tread - Embodied energy (kWh/kg):	0.1		5.9248
Riser height (m):	0.19	Riser width (m):	0.95		
Riser thickness (m):	0.012			Volume =, or insert value (m3):	0.036822
Riser - Density (kg/m3):	700	Riser - Embodied energy (kWh/kg):	0.1		2.57754
Staircase length (m):	4.9				
String depth (m):	0.25	String thickness (m):	0.025	Volume =, or insert value (m3):	0.06125
String - Density (kg/m3):	700	String - Embodied energy (kWh/kg):	0.1		4.2875
				Embodied energy =	25.57968
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 =	25.57968
Roof					
Area of roof (excluding openings) (m2):	55.08	Area, parallel to ceiling plane (m2):	44.89		
Roof length (m):	8.1				
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):	1.745008099
Outer finish - Density (kg/m3):	700	Outer finish - Embodied energy (kWh/kg):	0.28		684.0431746
Waterproof Layer - Density (kg/m3):	400	Waterproof Layer - Embodied energy (kWh/kg):	4.5		495.72
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):	0.1156	Number of trusses or joists, actual or:	15		
Volume per batten (m3):	0.006	Number of battens:	42	Volume =, or insert value (m3):	3.6384
Timber Density (kg/m3):	700	Timber - Embodied energy (kWh/kg):	0.1		254.688
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):	30.294
Insulation - Density (kg/m3):	24	Insulation - Embodied energy (kWh/kg):	0.49		356.25744
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):	0.66096
Internal finish - Density (kg/m3):	600	Internal finish - Embodied energy (kWh.kg-1):	0.5		396.576
				Embodied Energy - Roof =	2187.284615
					298.5008059
					298.5008059
Anticipated percentage of construction waste (%):	2.5	Typical practice = 10, Best practice = 2.5		Embodied Energy - Dwelling =	298.5008059
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 =	305.963326
Embodied CO2					
Percentage of fuel that is Electricity (%):	33.33	Emission Factor (kgCO2.kWh-1):	0.59		60.16677017
Percentage of fuel that is Gas (%):	33.33	Emission Factor (kgCO2.kWh-1):	0.19		19.37573955
Percentage of fuel that is Petroleum (%):	33.33	Emission Factor (kgCO2.kWh-1):	0.27		27.53394567
Percentage of fuel that is Coal (%):		Emission Factor (kgCO2.kWh-1):	0.31		0

Ecological Weight - Em CO2 =	107.0764554

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 =	24.263
Energy Generation: Inhab =	25.007
Ventilation =	0.450
Airtightness =	0.170
Ecological Wght: Embodied Energy =	305.96
CO2 Emissions: Inhab =	13.772
Lifespan =	120.000
Pollution: Energy Con Inhab =	5.945
Thermal Performance: U-roof =	0.08
Thermal Performance: U-wall =	0.12
Thermal Performance: U-floor =	0.10
Thermal Performance: U-window =	0.80
Thermal Performance: U-door =	0.55
Ecological Wght: Embodied CO2 =	107.08
Other Greenhouse Gas Emissions =	0.000
Water Consumption: Total =	38.300
Water Consumption: Potable =	25.941

Scoring

Energy Consumption: Inhab =	1.8382
Energy Generation: Inhab =	0.5555
Ventilation =	0.1600
Airtightness =	0.1590
Ecological Weight: Embodied Energy =	0.2500
CO2 Emissions: Inhab =	0.2067
Lifespan =	0.1260
Pollution: Energy Con Inhab =	0.0164
Thermal Performance: U-roof =	0.0104
Thermal Performance: U-wall =	0.0250
Thermal Performance: U-floor =	0.0122
Thermal Performance: U-window =	0.0074
Thermal Performance: U-door =	0.0008
Ecological Weight: Embodied CO2 =	0.0311
Other Greenhouse Gas Emissions =	0.0340
Water Consumption: Total =	0.0175
Water Consumption: Potable =	0.0052
Score =	**96.12**

Life Cycle Energy Consumption and Cost

Embodied Energy, annual equivalent =	2.549694384
Energy Cosumption: Inhabitation =	24.26324131
Embodied CO2, annual equivalent =	0.892303795
CO2 Emission: Inhabitation =	13.77242768
Gross Energy Consumption (kWh) =	406795.1
Net Energy Consumption (kWh) =	27403.1

Refer to Table Z for energy costs and standing charges

Primary Space Heating fuel cost (£.kWh-1):	0.0594	14683.2
Secondary Space Heating fuel cost (£.kWh-1):		0.0
Water Heating fuel cost (£.kWh-1):	0.0594	22953.9
Pumps and fans fuel cost (£.kWh-1):	0.0594	13647.9

Lights and Appliances fuel cost (£.kWh-1):	0.0594		29002.5
Cooking fuel cost (£.kWh-1):	0.01295		1896.9
Gas Standing Charge, if applicable (£.annum-1):	25.5675		12483.5
Electricity Standing Charge, if applicable (£.annum-1):	34.2969		16745.7
		Total Energy Cost (£)=	111393.62
		Lifecycle Cost per Unit Floor Area (£.m-2) =	881.07
		Lifecycle Cost per Unit Floor Area per Annum(£.m-2) =	7.34

Life Cycle Water Consumption and Cost

Potable water consumption (litres) =	6821951.9
Total water consumption (litres) =	10072134.0

Refer to Table AA for water costs and standing charges

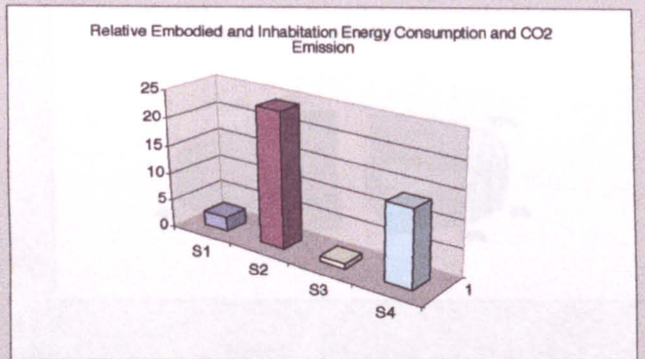
Potable water costs (£.l-1):	0.000704		19541.13
Sewerage water costs (£.l-1):	0.000510		14156.21
Potable Standing Charge, if applicable (£.annum-1):	25.70		12547.06
Sewerage Standing Charge, if applicable (£.annum-1):	11.31		5521.10
Highway & Drain Standing Charge, if applicable (£.annum-1):	68.89		33634.71
		Total Water Cost (£)=	85400.20
		Lifecycle Cost per Inhabitant (£.m-2) =	14233.37
		Lifecycle Cost per Inhabitant per Annum (£.m-2) =	118.61

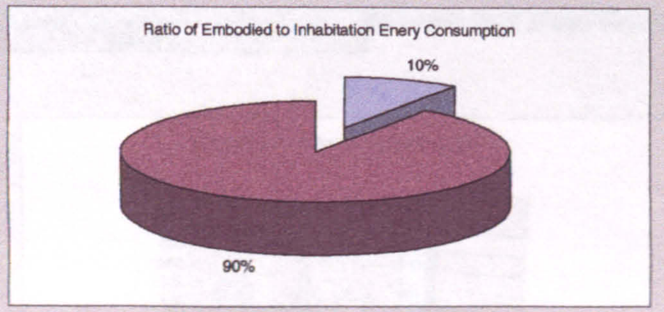
Life Cycle Energy Consumption

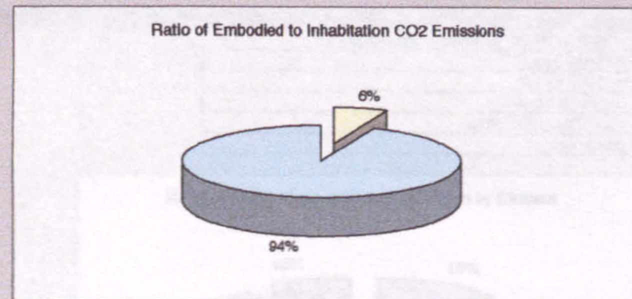
Gross Energy Consumption (kWh) =	406795.1
Net Energy Consumption (kWh) =	27403.1

Relative Embodied and Inhabitation Energy Consuption and CO2 Emission

Embodied Energy, annual equivalent (S1) =	2.549694384
Energy Cosumption: Inhabitation (S2) =	24.26324131
Embodied CO2, annual equivalent (S3) =	0.892303795
CO2 Emission: Inhabitation (S4) =	13.77242768

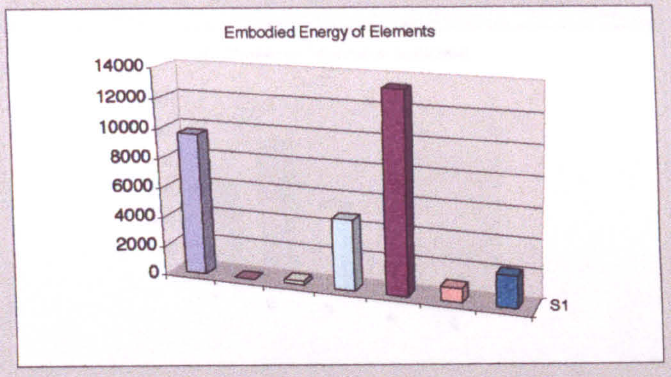


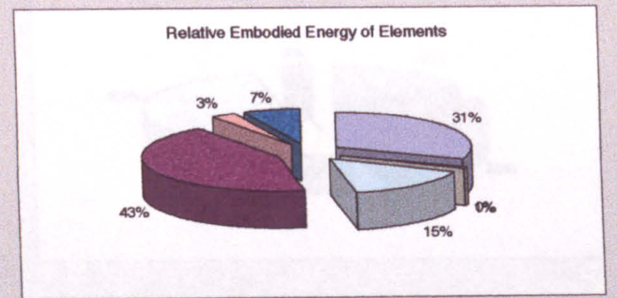




Relative Embodied Energy by Dwelling Element

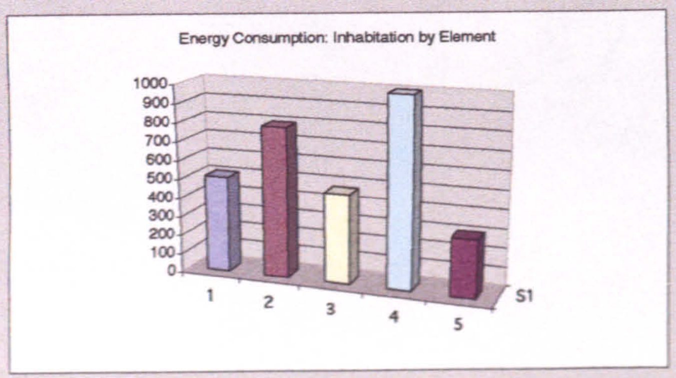
Total embodied energy =	305.963326
Foundations =	9611.18
Frame =	0.00
Ground floor =	243.57
Walls =	4783.001767
Glazing =	13413.88
Internal floors =	965.9099192
Roof =	2187.284615

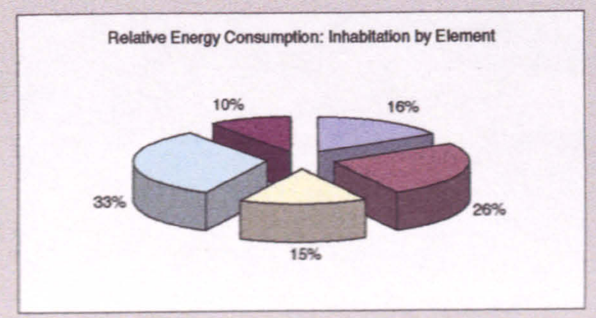




Relative Energy Consumption: Inhabitation by Element

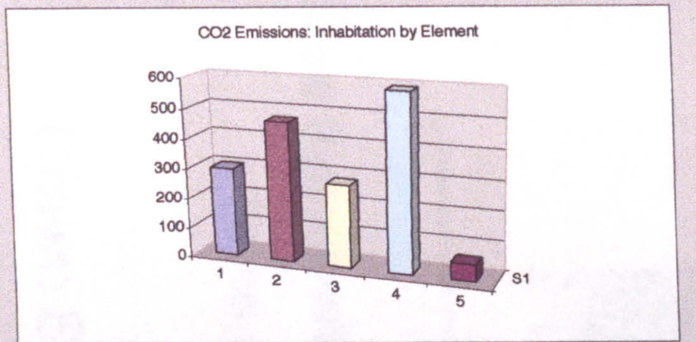
Total Energy Consumption: Inhabitation =	24.26324131
Space heating =	505.5818598
Water heating =	791.4444444
Pumps and fans =	470.5752942
Lights and appliances =	1000
Cooking =	300

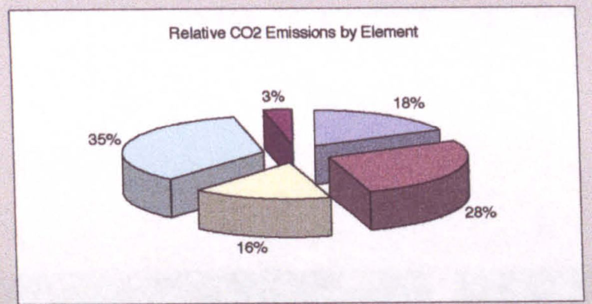




Relative CO_2 Emissions: Inhabitation by Element

Total Energy Consumption: Inhabitation =	13.77242768
Space heating =	298.2932973
Water heating =	466.9522222
Pumps and fans =	277.6394236
Lights and appliances =	590
Cooking =	57





Drawn Study Six, Seven & Eight

Individual Benchmark Analysis of Drawn Studies Six, Seven and Eight by Manual Calculation

Individual Benchmark Analysis of Drawn Studies Six, Seven and Eight by Manual Calculation

The following presents an analysis of the three Drawn Studies for the Ancoats site for each of the criteria that define the 'urban house in paradise', determining the benchmarks by manual calculation. Calculating each of the benchmarks by hand that were evaluated by the tool will validate the accuracy of the tool's prediction when the same benchmark is measured by an alternative methodology.

Carbon Dioxide Emissions: Inhabitation

The Energy Consumption: Inhabitation benchmark, determined below, established a total energy consumption of 24.17 $kWh.m^{-2}.a^{-1}$. The CO_2 emission factors can be used to convert this value into the CO_2 Emission: Inhabitation benchmark.

electricity	= 21.79 x 0.59	= 12.86 $kgCO_2.m^{-2}.a^{-1}$
gas	= 2.37 x 0.19	= 0.45 $kgCO_2.m^{-2}.a^{-1}$
		= 13.31 $kgCO_2.m^{-2}.a^{-1}$

Therefore the gross CO_2 emissions from fuel consumption are above the benchmark of the 'urban house in paradise'. The emissions saved through the renewable generation from the photovoltaics can be determined as:

generated	= 25.0 x 0.59	= 14.75 $kgCO_2.m^{-2}.a^{-1}$
net	= 13.31 – 14.75 = - 1.44 $kgCO_2.m^{-2}.a^{-1}$	

Thus, in terms of direct net CO_2 emissions, the dwelling has negative emissions.

The indirect CO_2 emission from the mains water consumed within the dwelling can be determined through the Water Consumption: Inhabitation benchmark. The potable consumption is calculated under the Water Consumption: Inhabitation benchmark below as 25.4 $l.p^{-1}.d^{-1}$, and therefore for the dwelling would be 55,664.1 litres per annum. The CO_2 emission arising as a consequence of mains water is 4.959 x 10^{-4} $kgCO_2.l^{-1}$; therefore the consequent emissions for the potable water consumed by the drawn study will be 27.6 $kgCO_2.a^{-1}$, or in terms of the floor area of the dwelling 0.40 $kgCO_2.m^{-2}.a^{-1}$.

The area of green space within the plot of the dwelling is 72 m^2. The CO_2 assimilation for green space is to 0.66 $kgCO_2.m^{-2}.a^{-1}$. Therefore the potential assimilation for the dwelling is

47.5 $kgCO_2.a^{-1}$, or in terms of the floor area of the dwelling 0.38 $kgCO_2.m^{-2}.a^{-1}$.

Therefore, the overall benchmark for CO_2 Emissions: Inhabitation is 13.52 $kgCO_2.m^{-2}.a^{-1}$ gross and -1.4 $kgCO_2.m^{-2}.a^{-1}$ net.

Carbon Dioxide Emissions: On Site Construction Processes

The benchmark analysis determined that the energy consumed during construction on site is typically 15 percent of the total embodied energy of the dwelling, depending upon the balance of fuel types, the consequential CO_2 emissions will vary by the same ratio. Also from the benchmark analysis, a mean value of emission for a typical of fuel types used during the construction of a dwelling is derived from Howard;[1] this equates to a value of 0.36 $kgCO_2.kWh^{-1}$. If data were available on the specific process that would take place on site during the construction and demolition of the dwelling, then a more accurate value could be determined which would take account of the different mix of fuel types used on site, and their corresponding emission factors. This would enable a validation of the 15 percent ratio to be made. As the scope of the research has not enabled this, the benchmark will be based upon the percentage ratio.

$$312.7 \times 0.15 = 46.8\ kWh.m^{-2}$$

$$249.8 \times 0.15 = 37.5\ kWh.m^{-2}$$

$$46.8 \times 0.36 = 16.9\ kgCO_2.m^{-2}$$

$$37.5 \times 0.36 = 13.5\ kgCO_2.m^{-2}$$

	Carbon Dioxide Emissions ($kgCO_2.m^{-2}$)
With basement included:	16.9
With basement excluded:	13.5

Carbon Dioxide Emissions: On site Construction Processes benchmark for Drawn Study 7

Carbon Intensity

The carbon intensity can be estimated using the following equation:

$$CI = Cd / \eta$$

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

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

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

η = coefficient of performance (%)

Therefore, for the heating system of the urban house in paradise:

CI = Cd / η

carbon content of mains electricity = 0.75 $kgCO_2.kWh^{-1}$; carbon content of renewable generated electricity = 0.0 $kgCO_2.kWh^{-1}$.

efficiency of Genvex unit = 240 percent.

∴ CI = 0.75 / 2.4, or 0 / 2.4

= 0.31 $kg.kWh^{-1}$ or 0 $kg.kWh^{-1}$, depending upon if electricity being consumed is mains or renewably generated.

For the dwelling to achieve the benchmark of the 'urban house in paradise', of ≤0.24 $kg.kWh^{-1}$, the heating system would have to use renewably generated electricity for at least 33 percent of its operating time, which is continual; this would bring the mean carbon intensity value to 0.24 $kg.kWh^{-1}$. If using a balance of equal generation to consumption, which the dwelling is, the benchmark is 0 $kg.kWh^{-1}$.

Construction Period

Within the scope of the Studies, it has not been feasible to predict the time that would be required to construct the dwelling on site. Prefabrication of the wall panels would increase the rate of construction; if the dual leaf walls are created as a single, storey high sandwich panels, the dwelling could be composed from 12 panels. Each of the four panels that make up each floor would be craned into place, and then trimmed with the header joists, from which the internal floor of the next storey would be hung. The roof could also be prefabricated in two panels, and craned into place. It could be speculated that the envelope of the dwelling could be assembled in 1 week.

The inclusion of the basement would protract the construction period. It would require additional excavation, the concrete slab would have to be poured and cured, and additional block walling, in comparison to the depth required on the foundations, would have to be built. The additional time could be reduced through lining the basement in pre cast concrete panels; this is a method used to build the Huf Haus dwellings, for which the basement is completed in 2 weeks. If 3 weeks are allowed for internal finishing, then the dwelling could be completed in 6 weeks.

Contextual Significance of the Site

A historical analysis of the site was conducted during the early stages of the design process; this is summarised in the plans on sheet one of Drawn Study Six. The contextual response is threefold. Firstly the existing block structure of the surrounding urban fabric is extended over the masterplan at the edges toward the city centre, in order to stitch the new and existing together. The most significant access to the site orientates itself to this grain and originates within the existing part of it; its axis flows through an existing arch in a fragment of the original wall surrounding the edge of the site, which is retained. Another edge is created against the existing canal, which is one of the only other historical elements remaining on the site; where the geometry of the historical grid and the canal meet, the principal urban square is created; a pivot about which the geometry hinges. The second response to the context of the site is the excavation of parts of the canal that have previously been filled in; the intention, rather than pure historicism, is to extend the network of routes that cross the site as canal towpaths for pedestrians and cyclists. In the three dimensional morphology of the site, the vertical mass of the surrounding fabric is carried onto the masterplan as the third contextual response, ensuring that the density at the edges of the site next to the city centre is directly comparable to the most historically and contextually significant existing fabric. Therefore it is considered that the design does fulfil the benchmark demand.

Deconstruction and Demolition: Recycling of Materials

It is proposed that any masonry from the demolition of existing buildings on the site will be reused or recycled. Where the material is contextually significant, and the mortar bonding sufficiently weak that the bricks can be broken apart, the material will be reused. Other masonry and concrete can be crushed to form aggregates for new concrete and in sub-base for road construction. Roof tiles can also be reused or recycled according to the same classification. In terms of embodied energy, reusing a material is preferable to it being recycled. Although a specific breakdown of the materials that would arise could not be established, it could be speculated that, from precedent, with the significant quantity of masonry construction used in the surrounding buildings and the right waste management strategy the benchmark of 85 percent could be achieved.

Design Life Span

The British Standards require that any dwelling has a design life expectancy of 60 years, therefore it can be assumed that a timber frame dwelling can achieve that value. The Timber Research and Development Association consider that under the correct conditions, achieving a life span of 120 years would not present difficulties;[2] there are examples of timber frame buildings that substantiate this is possible. The critical factor is quality of detailing, and in two areas in particular. The first is around junctions and openings to ensure that moisture is shed from the fabric and does not collect, causing rot. Secondly, a cavity should be provided between the external skin and the breather membrane that will allow any moisture to escape or evaporate. This is proposed within the Drawn Study, created by the vertical battens to which the external boarding is fixed. Therefore, it is assumed, without further clarification being possible, that the structure of the dwelling can, at least theoretically, achieve the benchmark of 120 years.

The *Life Expectancies of Building Components* gives a mean value for external boarding of 33 years.[3] Therefore it is assumed that the external boarding will have to be replaced periodically during the life span of the dwelling. The replacement can be included within the embodied energy assessment. 120 / 33 = 3.6. Therefore it is assumed that the boarding will be replaced four times.

Density

Of the 11.68 hectares of the site 6.31 hectares are used for housing. This value can be used to calculate the net residential density of the masterplan. Four scenarios of building morphology and balance of dwelling types were developed in Drawn Study 6. This served to test how the benchmark was affected through varying the balance of houses and flats, and the vertical scale of the masterplan proposed. The four scenarios are summarised overleaf.[4]

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[2] Personal communication with technical representatives of Timber Research and Development Association, 1 August 2000.

[3] 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.

[4] An occupancy level of 2 people per flat and 4 people per house is assumed. This equates to a mean of 2.1 people per dwelling; although below that national mean of 2.4 this seems appropriate due to the high proportion of flats. The net residential area is 6.31 Ha.

Scenario	Houses	Flats	Inhabitants	**Density (p.ha^{-1})**
1	148	696	1984	**314**
2	37	1144	2436	**386**
3	0	1264	2528	**401**
4	0	1583	3166	**502**

Density scenarios for Drawn Study Six

The second scenario was adopted, as it was closest to the 'urban house in paradise' benchmark and therefore demonstrated the nature and scale of the built form required to achieve the benchmark, giving a net residential density benchmark of 386 p.ha^{-1}.

Diversity

Almost half of the total floor area proposed in the Study is allocated for non-dwelling functions. 62,000 m^2 of floor space is proposed for functions other than dwelling within the masterplan. Of this, 51,00 m^2 is proposed as commercial, which will include retail, leisure and office space. Other functions that will contribute to the programmatic diversity are a kindergarten, medical centre, cafés and bars, restaurants and a gymnasium. Light industrial spaces included in the plan are located toward the southeast edge of the site.

A portion of the site was studied, to establish a guideline benchmark for the first phase. The total floor area of buildings in which functions other than dwelling was calculated, including those in which the ground floor is proposed as mixed function with residential over. The number of functions was estimated by accounting for the space requirements of a blend of the functions described and the total floor area available; the benchmark was estimated using the following equation.

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

= 100.8 / 1.8

= 56

Therefore the benchmark is quantified at 56 functions per hectare.

Domestic Waste

A large number of kitchen units are included within the plan. It is proposed that two be dedicated to storage for segregating and storing recyclable material and domestic refuse.

As the dwellings are terraced, there is a 2.0 m^2 external store at the front of the dwelling into which the separated waste can be placed for collection. The organic putrescible waste from the kitchen and garden can be placed directly onto a compost heap in the rear garden, which can also be used to dispose of the odourless produce of the WC composter.

With a total of 1,181 dwellings housing 2,432 inhabitants on the site, each of which producing a predicted 7.2 kilogrammes of recyclable material per week, 17.5 tonnes of recyclable material will need to be collected, possibly separated further, and either processed on or transported from the site each week. This is a source of potential employment generation and light industrial space use on the site.

Ecological Significance of the Site

Previously an area of warehouses surrounding the Rochdale Canal, the site is 100 percent brownfield. The majority of the site is already flat, the warehouse having been demolished. The remainder are either vacant, or are areas that are occupied. These latter areas are within the last phases of the masterplan, and will come into effect as the existing buildings reach the end of their life span.

There are very few green areas within the site, and with no evidence of an existing number of species of either animal or vegetation. The use of the site as a car park has ensured that no vegetation could establish itself. The canal supports a small number of species of wildfowl; these will be enhanced through the cleaning and upgrading of the canal as a part of the works. The canal does not fall under the categories of bodies of water that have to be accounted for by the benchmark, as it is man-made. Therefore the site complies with the benchmark in terms of both land category and existing features.

Ecological Weight: Embodied CO_2 Emissions

As the exact fuel ratios for different materials have not been able to be determined, the embodied CO_2 emissions will have to be calculated using a mean value. From the benchmark analysis, a mean value of emission for a typical of fuel types used during the construction of a dwelling is derived from Howard;[5] this equates to a value of 0.36 $kgCO_2.kWh^{-1}$. If such data were available, then a more accurate value would be able to be determined. This would take the embodied energy of each material, and split that value between the ratios of different fuels used in the extraction, production and transportation of that material.

However using the embodied energy value, calculated in the next benchmark, a best approximation can be determined as follows:

$$312.7 \times 0.36 = 112.6\ kgCO_2.m^{-2}$$

$$249.8 \times 0.36 = 89.9\ kgCO_2.m^{-2}$$

	Embodied CO_2 Emissions ($kgCO_2.m^{-2}$)
With basement included:	112.6
With basement excluded:	89.9

Embodied CO_2 Emissions for Drawn Study 7

Using an assumed ratio of one third for each fuel type, the embodied CO_2 emissions can be calculated as follows:

(0.33' x 312.7) x emission factors

(0.33' x 249.8) x emission factors

	Embodied CO_2 Emissions ($kgCO_2.m^{-2}$)			
	Electric	Gas	Petroleum	**Total**
With basement included:	61.5	19.8	28.1	109.4
With basement excluded:	49.1	15.8	22.5	87.4

Embodied CO_2 Emissions for Drawn Study 7, by fuel type

From this it can be concluded that using the assumption of a third for each fuel type leads to an embodied CO_2 benchmark 3 percent below that of the mean value derived from Howard. This confirms that the methodology adopted in the prioritising of the criteria was accurate.

Ecological Weight: Embodied Energy

The calculation of this benchmark was achieved through a detailed analysis of the volume of the materials used to construct the dwelling element by element, such as roof, external walls and internal floors, using the drawings in Drawn Study 7. The volume of each material was

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

then converted into its mass using standard densities, and then into the embodied energy value using standard values of embodied energy per kilogram. A summary of this analysis is presented in the table at the end of this section.

As the inclusion of the basement is solely as a consequence of the Water Consumption: Inhabitation benchmark, the analysis included scenarios of the embodied energy both with and without the basement. In the case of the latter, a concrete strip foundation replaced the basement walls. The embodied energy values are as follows:

	Embodied Energy	
	Total (kWh)	per unit area ($kWh.m^{-2}$)
With basement included:	39,538.7	312.7
With basement excluded:	31,585.2	249.8

Ecological Weight: Embodied Energy for Drawn Study 7

Energy Consumption: Construction Processes

The benchmark analysis determined that the energy consumed during construction on site is typically 15 percent of the total embodied energy of the dwelling. The scope of this study has not enabled a more detailed analysis of the specific processes used on site during the construction of the Drawn Study dwelling, and therefore the value of this benchmark will have to be based upon the percentage. A worthwhile study, if the dwelling were to be constructed, would analyse the on site processes, such as plant consumption from excavation of erection of the timber frame panels, and make a detailed evaluation of the energy they use. This would enable a validation of the 15 percent ratio to be made.

$$312.7 \times 0.15 \quad = 46.9 \text{ kWh.m}^{-2}$$

$$249.8 \times 0.15 \quad = 37.5 \text{ kWh.m}^{-2}$$

	Energy Consumption: Construction ($kWh.m^{-2}$)
With basement included:	46.9
With basement excluded:	37.5

Energy Consumption: Construction Processes benchmark for Drawn Study 7

Energy Consumption: Inhabitation

The Standard Assessment Procedure (SAP) worksheet is used to validate the energy consumption due to space and water heating; this is to ensure that the algorithms in the spreadsheet are correct. The completed worksheets are located at the end of this section. Answer 51 gives the energy requirement for water heating as 2.86 $GJ.a^{-1}$; answer 81 gives the space heating energy requirement as 1.77 $GJ.a^{-1}$; answer 87 gives the energy consumption due to pumps and fans as 1.69 $GJ.a^{-1}$. These three values can be converted into $kWh.m^{-2}.a^{-1}$,[6] to become 6.28, 3.90 and 3.71 $kWh.m^{-2}.a^{-1}$ respectively.

The energy consumption of lights and appliances and cooking is based upon the most efficient scenario in *GIR 53*, which can be equated to 7.91 and 2.37 $kWh.m^{-2}.a^{-1}$; this reduced demand is achieved through appliance selection and prudent management by the inhabitants.[7]

These values are summed to calculate a total Energy Consumption: Inhabitation value for the dwelling, of 24.17 $kWh.m^{-2}.a^{-1}$. The 0.7 percent deviation between this value and the benchmark calculated by the assessment tool can be attributed to rounding during the SAP calculation.

Energy Generation: Inhabitation

The area of photovoltaic panels on the roof plane is 16.0 m^2. The pitch of the roof plane is dictated by the angle most suitable for generation, which can be determined by subtracting the latitude of the site from 90, which for Manchester gives a pitch of approximately 38 degrees. This value was reduced to 35 for two reasons; firstly to make slightly more efficient use of summer sum which is more prevalent than winter sun, when the altitude is higher, and secondly to ensure that the internal volume of the third floor is not excessive, which would result in greater energy consumption by the ventilation system.

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 from data provided

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[6] 1 kWh is the equivalent of 3.6 x 10^6 J; Muncaster, Roger. *A-Level Physics*, Cheltenham: Stanley Thornes (Publishers) Limited, 1989.

[7] BRECSU. 'Building a Sustainable Future - Homes for an Autonomous Community,' *General Information Report 53*, London: Construction Research Communications Limited, October 1998.

for the mean annual energy available for a variety of locations, which is 1,050 $kWh.m^{-2}.a^{-1}$ for Manchester. The actual energy that will be provided by the panels will be dependent upon their efficiency; a typical value for which is 19 percent.[8] 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.

energy generation =	16 x 1050 x 0.19 =	3192 $kWh.a^{-1}$
generation per unit floor area =		25.25 $kWh.m^{-2}.a^{-1}$

Green Space

Over the whole site, for the density scenario chosen, the total floor area of the dwellings was calculated using the breakdown of dwelling types and the Space Standards: Area benchmark, which are for the houses are calculated below; the area of flats was based upon the Space Standards: Area benchmark of the 'urban house in paradise'.

37 houses	
(12 x 105.5) + (12 x 126.4) + (13 x 126.4)	= 4,426 m^2
1,144 flats	
(1,144 x (2 x 27))	= 61,776 m^2
Floor area =	= 66,202 m^2, 66.2 Ha

Within the plan 1.45 ha of land has been proposed as green space, as either strategic open space, semi-private gardens around apartment blocks, or as private gardens. Therefore the proportion of green space to the floor area of the dwellings can be calculated in the following equation.

14,500 / 66,202 = 0.22

Therefore the benchmark for the overall site can be quantified as 22 percent.

For Drawn Study 7, the area of the rear garden is 72 m^2. As the floor area of the dwelling is 126.4 m^2 for the individual dwelling the Green Space benchmark is 57 percent.

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

Lifecycle Cost

The construction cost for the dwelling has been estimated by the quantity surveyors Davis Langdon Everest at 1,386.76 £.m^{-2}. This can be translated into an annual cost across the design life span of the dwelling of 11.56 £.m^{-2}.a^{-1}. A variation on the capital construction cost, excluding the basement and water saving appliances was also studied by Davis Langdon and Everest, equating to 1,200.06 £.m^{-2}, or 10.00 £.m^{-2}.a^{-1} across the design life span of the dwelling.

The lifecycle energy cost of the dwelling can be calculated from the consumption values given by the tool, which are validated above to be accurate. The cost will be calculated firstly on the basis of fossil fuels providing the energy; this will provide a value against which to see the cost effectiveness of energy generation. The first year's energy costs can be calculated as follows:

Function	(kWh.m^{-2})	Fuel	Cost (p.kWh^{-1})	Cost (£.m^{-2}.a^{-1})
Space Heating	4.0819	elec	5.940	0.2425
Hot Water	6.2599	elec	5.940	0.3718
Pumps and fans	3.722	elec	5.940	0.2211
Cooking	2.3729	gas	1.295	0.0307
Lights and App's	7.9095	elec	5.940	0.4698
Total				**1.3359**

Energy consumption and costs for the dwelling

The assumption of a 2 percent annual increase in fuel costs, as used in the Lifecycle Cost benchmark, was used to predict these costs over the design life span of the dwelling. The outcome of this analysis is that the predicted lifecycle energy cost for the dwelling is 7.36 £.m^{-2}.a^{-1}.

The spreadsheet also showed that the total cost of electrical consumption is 6.13 £.m^{-2}.a^{-1}. This means that over the life span of the dwelling, if this cost of mains electricity were saved, £93,056 would be available for energy generation equipment; this value does not include excess energy that could be sold back to the electricity supplier.[9] Also analysed was the

[9] A precedent has now been established with a utility company where electricity is bought by the supplier for the same cost as it is generated, in effect a two way meter; previously suppliers would only

energy cost if the consumption were that of a typical three bedroom semi-detached dwelling; this equated to 19.30 £.m^{-2}.a^{-1}. Therefore, the saving over the life span of the dwelling was predicted as £181,148.90, more than the capital construction cost of the dwelling. Even ignoring the increase in fuel cost, discounting standing charges which apply to both scenarios, and basing the saving on current fuel consumption costs this would equate to a saving of £62,263 over the life span of the dwelling.

The potable water consumption of the dwelling is 28.92 l.p^{-1}.d^{-1}. The analysis shows that the predicted water cost over the life span of the dwelling is 123.95 £.p^{-1}.a^{-1}. If the typical benchmark level, of 160 litres per person per day, were consumed, the cost would be 359.80 £.p^{-1}.a^{-1}; over the life span of the dwelling, this equates to a fiscal cost saving of £28,302 per person, or £67,925 based on the mean occupancy figure of 2.4 people.

Davis Langdon Everest also predicted the construction cost for the dwelling if it was constructed using traditional methods; this was £98,900. Therefore the difference in capital construction costs between a traditionally built dwelling and one built to the ecological performance of the drawn study is £76,400. However, the cost savings achieved through the reduction in energy and water consumption over the life span of the dwelling are £249,074. If this increase in capital cost were applied to the 3.8 million new dwellings required by 2021, the additional cost would be £195.2 billion, 42 times the Government's proposed spending on housing for 2003/04.[10] However, if the capital cost were based upon the estimate excluding the basement, and therefore focussing upon Energy Consumption: Inhabitation, Energy Generation: Inhabitation, Ecological Weight and CO_2 Emissions: Inhabitation,[11] which are the most significant for increasing the ecological sustainability of the dwelling, the cost would be £134.9 billion. 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.

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buy electricity back at a lower rate than they supplied it, making generation less cost effective. Personal Communication with Stephen Bandy of Dewhurst MacFarlane Engineers, 5 April 2000.

[10] Department of the Environment, Transport and the Regions. Our Towns and Cities: The Future – Delivering an Urban Renaissance, London: HMSO, November 2000.

[11] 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.

Nitrogen Oxide Emissions from Gas Boilers

The benchmark for nitrogen oxide (NO_X) emissions relates to gas boilers only. As a Genvex unit, which is electrically powered, provides space and water heating this benchmark will not be relevant. Alternatively, it could be considered that this benchmark is zero.

Other Greenhouse Gas Emissions

The cellulose fibre insulation specified for the dwelling will not use a greenhouse gas material as its blowing agent. Therefore the benchmark for Other Greenhouse Gas Emissions is 0 kgHCFC.

Pollution Emissions: Energy Consumption Inhabitation

The benchmark is determined according to the proportion of each fuel type consumed of the overall energy consumption.

proportion of total	= consumption by fuel / Energy Con: Inhabitation	
electricity	= 21.79 / 24.16	= 0.902
gas	= 2.37 / 24.16	= 0.098

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

electricity	= 0.902 x 6.494	= 5.858
gas	= 0.098 x 0.879	= 0.086
		= 5.944

Therefore the gross benchmark will be 5.944 $g.kWh^{-1}$. However, a net value will take account of the energy generated by the dwelling.

25.0 / 24.16	= 1.035
1.035 x 6.494	= 6.720
5.944 – 6.720	= -0.766

Therefore the net benchmark would be -0.766 $g.kWh^{-1}$.

Procurement Strategy

This criterion is based upon proposing a strategy for realising the 'urban house in paradise', as opposed to a benchmark for its performance. The design process for the Drawn Study has, in many respects followed that process, through using the benchmarks as a performance specification, and refining the design in order to achieve them. For example, the thermal performance was increased above the target benchmark standard, in order to reduce heat loss and thereby to achieve the target for energy consumption during inhabitation. Furthermore, the addition of the basement to include water storage was detrimental to the embodied energy of the dwelling, which is a criterion with a higher significance weighting than that of the water consumed during inhabitation. This fact can be used to deduce that in terms of the overall ecological sustainability of the dwelling, the basement should be excluded. Therefore, rather than establishing if the benchmark can be achieved, this criterion demonstrates the way in which a performance specification, in the form of the profile of benchmarks and their collective assessment, can be utilised to achieve the most ecologically sustainable refinement of the design.

Other Ecological Impacts of Materials

Timber from a renewable source, which is specified throughout the dwelling, will achieve an 'A' rating in the *Green Guide to Housing Specification*, as would cellulose fibre insulation. Reusing roof tiles will also ensure compliance with the benchmark. The only problematic materials will be in-situ concrete and the concrete block walls of the basement, if included. Recycled aggregates would be specified wherever possible, and a manufacturer of the concrete blocks who uses recycled materials sought. Therefore, in particular is the variant of the dwelling without the basement is considered, the benchmark performance will be 'A' for all materials.

Quality of the Internal Environment: Daylight

The average daylight factor of a space can be determined at the design stage by the following equation:[12]

$$DF (\%) = (M \,.\, W \,.\, \theta \,.\, T) / (A \,.\, (1- R^2))$$

where W = total glazed area of windows
A = total area of all room surfaces (ceiling, floor, walls, windows)
R = area-weighted average reflectance of the room surfaces
M = correction factor for dirt and glazing bars
T = glass transmission factor
θ = angle of visible sky

guide values for these variables are:[13]

R = 0.5
M = 1.0 for vertical glazing that can be easily cleaned
0.8 for inclined glazing
0.7 for horizontal glazing
T = 0.6

For living spaces, (the lounge, dining and kitchen areas are considered as one space):

W = 10.5
A = 158.2
R = 0.5
M = 1.0
T = 0.6
$\theta = 65^\circ$

DF = $(1.0 \times 10.6 \times 65 \times 0.6) / (158.2 \times (1- 0.5^2))$
= **3.5 %**

For bedroom 1:

W = 6.2
A = 76.2
R = 0.5
M = 1.0
T = 0.6
$\theta = 67^\circ$

DF = $(1.0 \times 6.2 \times 67 \times 0.6) / (76.2 \times (1- 0.5^2))$
= **4.3 %**

12 Littlefair, P. J. 'Average Daylight Factor: A Simple Basis for Daylight Design', *IP15/88*, Building Research Establishment, November 1988.
13 Prior, J. J. and Paul B. Bartlett. *Environmental Standard – Homes for a Greener World*, Garston: Building Research Establishment, 1995.
14 BRECSU. 'Review of Ultra-Low-Energy Homes - A Series of UK and Overseas Profiles,' *General Information Report 38*, London: HMSO, February 1996.

For bedroom 2:

$W = 5.8$
$A = 66.8$
$R = 0.5$
$M = 1.0$
$T = 0.6$
$\theta = 67^{o}$

$DF = (1.0 \times 5.8 \times 67 \times 0.6) / (66.8 \times (1 - 0.5^2))$
$=$ **4.7 %**

For workspace / bedroom 3:

$W = 17.2$
$A = 176.4$
$R = 0.5$
$M = 1.0$
$T = 0.6$
$\theta = 72^{o}$

$DF = (1.0 \times 17.2 \times 72 \times 0.6) / (176.4 \times (1 - 0.52))$
$=$ **5.7 %**

Quality of the Internal Environment: Air Tightness and Ventilation

Because the value of the air tightness can only be validated after completion of the dwelling, the benchmark is based upon precedent. 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,[14] which is the benchmark of the 'urban house in paradise'. This dwelling was constructed using a similar construction technology. Dual leaf timber frame walls had and overall insulation thickness of 300 mm; they were finished externally in timber cladding; floors were suspended timber; windows were double glazed in timber frames. The roof was structural timber, with 350 mm insulation in the plane of the pitch. This dwelling proves that the benchmark target is achievable using timber frame construction.

The SAP assessment does provide a very basic assessment of structural infiltration; however, it was not considered sufficiently refined to assess the benchmark. A strategy was adopted in the design of the dwelling that based the construction detailing of precedents that have demonstrated similar performance to the benchmark target. Within the scope of the research, this was considered the most detailed that the evaluation of the benchmark could be. Should the evaluation be continued, the next step would be to consult a specialist on air tightness in building construction, to discuss refinements that would be required in the construction and detailing strategy to ensure that the benchmark is achieved.[15]

A mechanical ventilation system with heat recovery was specified for the dwelling, to ensure an adequate rate of air supply within a relatively airtight structure. The Genvex 'Combi' unit is capable of supplying air at a rate of up to 250 $m^3.h^{-1}$;[16] with a total internal volume of 427.2 m^3, the maximum air change rate would be 250 / 427.2, or 0.585 $ach.h^{-1}$. To achieve the 'urban house in paradise' benchmark of 0.45 $ach.h^{-1}$, the system would have to supply air at a rate of 192.2 $m^3.h^{-1}$, which is within the capability of the 'Combi' unit. Therefore the benchmark could be achieved.

Quality of the Internal Environment: Indoor Pollution

The benchmark for the 'urban house in paradise' requires that the interior of the dwelling uses none of the following materials medium density fibreboard (MDF), particleboard, chipboard, formaldehyde, lead based paints, preservative treated timber; also that urea-formaldehyde foam insulation is not used. Natural, as opposed to man-made, timber is used throughout the interior of the dwelling. The most probable use for man-made timber with polluting adhesives is for kitchen units and worksurfaces. In the Drawn Study, the kitchen units were specified as a softwood and the worksurfaces were specifically specified as beech, both from a sustainable source within the United Kingdom. As both of these are more expensive than the man-made counterparts, this has contributed to the increased cost of the dwelling over that of the construction cost benchmark.

Reduction of Construction Waste

Until the dwelling is constructed, it would not be possible to evaluate this benchmark, as the assessment requires measuring the quantity of waste produced as a proportion of the total quantity of material from which the dwelling is built. The latter can be calculated from the manual evaluation of the embodied energy of the dwelling as 94.5 tonnes; therefore to comply with the benchmark the maximum quantity of waste that could be produced is 2.4 tonnes.

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[15] A potential specialist would be Stuart Borland of Building Sciences Limited.
[16] Technical literature for the Genvex 'Combi' mechanical ventilation unit with integral water heating.

The majority of the dwelling would be prefabricated, including the wall and roof, and potentially the basement. The dwelling is proportioned upon a 900 mm module. Collectively these factors should ensure that the dwelling achieves the benchmark.

Recyclability of Building: Adaptability

The quantification of the benchmark value of adaptability is a measure of the number of internal load-bearing partitions in comparison to the total number of internal partitions. The structural engineer did not consider that any load-bearing partitions were required within the dwelling, and therefore the benchmark measured by the following equation.

Number of internal load-bearing walls/ total number of internal walls

$$= 0 / 9 \qquad = 0$$

Space Standards: Area

The internal habitable floor area of the dwelling is, 44.89 + 44.68 + 36.86 = 126.4 m^2. For a six person dwelling, the benchmark can be determined as:

$$126.4 / 6 \qquad = 21.1\ m^2.p^{-1}$$

For the 6.3 and 7.2 metre variant dwellings, the space standards were calculated in the same manner, and were established as 21.6 and 21.07 $m^2.p^{-1}$.

The proposed 'urban house in paradise' benchmark for a six person dwelling is 20.4 $m^2.p^{-1}$, a total of 122.4 m^2. As the analysis for the space standards benchmarks was predominantly based on two storey dwellings, if an allowance of 4 m^2 is made for additional circulation space for an extra storey, then the benchmark has been achieved. It should be noted that this benchmark is a minimum, and so it would have been acceptable for it to be over the proposed value; however, the purpose of limiting the area to the actual value of the benchmark was to show that this would provide an acceptable floor area for a six person dwelling. In addition, the prioritising of the criteria demonstrated that increasing the area of the dwelling has a detrimental effect on the ecological sustainability of the dwelling, due to the additional materials embodied in creating the additional area, and also the fuel used to heat and illuminate it.

For the 6.3 and 7.2 metre variant dwellings, the space standards were calculated in the same manner, and were established as 21.6 and 21.07 $m^2.p^{-1}$.

Space Standards: Volume

The internal habitable volume of the dwelling is 134.67 + 134.04 + 158.50 = 427.2 m^3. For a six person dwelling, the benchmark can be determined as:

$$427.2 / 6 \quad = 71.2\ m^3.p^{-1}$$

For the 6.3 and 7.2 metre variant dwellings, the space standards were calculated in the same manner, and were established as 64.8 and 70.6 $m^2.p^{-1}$.

The proposed 'urban house in paradise' benchmark for a six person dwelling is 61.2 m^2 per person, a total of 367.2 m^2. The volume of the Drawn Study is higher than that of the benchmark, by 60 m^3 or 10 $m^3.p^{-1}$. The reason for this is twofold; firstly it is due to the additional space of the circulation to the third storey, which at 4 m^2 in a space 4.3 m high is a volume of 17.2 m^3; the second, and more significant, cause is the roof profile. The area required for the photovoltaic array dictated the roof profile, and the space within this profile was included within the habitable volume of the dwelling. Should it transpire that this additional space was adversely affecting the energy consumption of the dwelling, due to the additional volume of air to be heated and ventilated, then a horizontal ceiling plane could be introduced, which would also create additional storage space within the dwelling.

Thermal Performance

The thermal performance of each element from which the envelope of the dwelling is composed is calculated individually. The equations used are taken from either the *CIBSE Guide A* or *Part L* of the Building Regulations.

Roof

The thermal performance of the roof fabric can be determined by the following equation:

$$U = 1 / (R_A . \cos\theta + R_{cav} + R_B)$$

Where R_A = Combined resistance of the materials in the plane of the pitched part of the roof
θ = Angle of roof pitch
R_{cav} = Resistance of roof void, if appropriate
R_B = Combined resistance of the materials in the plane of the horizontal, or ceiling, plane of the roof

The breakdown of the roof construction in the dwelling is:

	Thickness (m)	Conductivity (w.mK-1)
Concrete roof tile:	0.03	0.245
Waterproof layer:	0.0025	0.6
Joists:	0.6	0.14
Sheathing:	0.03	0.14
Insulation:	0.6	0.034
Internal finish:	0.012	0.46

Thermal resistance = R_{so} + (l / k) + (l / k) + ... + R_{si}

Where R_{so} = external surface resistance
L = material thickness (m)
K = thermal conductivity ($w.mK^{-1}$)
R_{si} = internal surface resistance

Therefore, R_A can be calculated as follows:

- Resistance through timber joists (R_t):

  0.04 + (0.03 / 0.245) + (0.0025 / 0.6) + (0.03 / 0.14) + (0.6 / 0.14) +

  (0.012 / 0.46) + 0.12

  = 4.81

- Resistance through insulation (R_{ins}):

  0.04 + (0.03 / 0.245) + (0.0025 / 0.6) + (0.03 / 0.14) + (0.6 / 0.034) +

  (0.012 / 0.46) + 0.12

  = 18.17

- Fractional area of timber (F_t):

  Joist width / joist centres

  = 0.05 / 0.6

  = 0.083

- Fractional area of insulation (F_{ins}):

  1 - fractional area of timber

  = 1 – 0.083

  = 0.917

- Total resistance, accounting for fractional area

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

  = 14.76

Therefore thermal performance of roof, U_{roof} =

$$1 / (14.76 \times \cos 35) \qquad = \mathbf{0.078\ W.m^{-2}.K^{-1}}$$

External Walls

The thermal resistance of the wall structure can be summarised in the following equation:

$$U = \quad R_{so} + (l / k) + (l / k) + \ldots + R_{cav} + R_{si}$$

The breakdown of the wall construction in the dwelling is:

	Thickness (m)	Conductivity ($w.mK^{-1}$)
Weather boarding:	0.02	0.14
Sheathing:	0.03	0.14
Outer leaf:	0.1	0.14
Insulation:	0.12	0.034
Inner leaf:	0.1	0.14
Internal finish:	0.012	0.46

The thermal resistance through the outer leaf can be calculated as:

- Resistance through timber studs

  $0.05 + (0.02 / 0.14) + (0.03 / 0.14) + (0.1 / 0.14)$

  $= 1.12$

- Resistance through insulation

  $0.05 + (0.02 / 0.14) + (0.03 / 0.14) + (0.1 / 0.034)$

  $= 3.35$

- Fractional area of timber:

  Stud width / stud centres

  $= 0.05 / 0.6$

  $= 0.083$

- Fractional area of insulation:

  1 - fractional area of timber

  $= 1 - 0.083$

  $= 0.917$

- Total resistance, accounting for fractional area

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

  $= 2.873$

The thermal resistance through the insulation can be calculated as:

l / k

$= 0.12 / 0.034$

$= 3.53$

The thermal resistance through the outer leaf can be calculated as:

- Resistance through timber studs

  $(0.1 / 0.14) + (0.012 / 0.46) + 0.12$

  $= 0.86$

- Resistance through insulation

  $(0.1 / 0.034) + (0.012 / 0.46) + 0.12$

  $= 3.09$

- Total resistance, accounting for fractional area

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

  $= 2.54$

Therefore, the total thermal resistance of wall, R_T =

$2.87 + 3.53 + 2.54 = 8.94$

Therefore, the total thermal performance of wall, U_{wall} =

$1 / 8.94$ = **0.11 W.m^{-2}.K^{-1}**

Ground Floor

The U-value of the structure of the ground floor can be determined by:

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

Where, λ_e = thermal conductivity of earth (1.4 W.m^{-1}.K^{-1})
b = breadth of floor (5.2 m)
l = length of floor (7.9 m)
w = wall thickness (0.4 m)

= 0.55 W.m^{-2}.K^{-1}

Accounting for the insulation of the ground floor:

$$U = 1 / ((1/ U_{floor}) + R_{ins})$$
$$1 / ((1/ 0.55_r) + (0.22 / 0.035))$$
$$0.123 \text{ W.m}^{-2}.\text{K}^{-1}$$

As the floor is suspended, these values are used in the following equations, from the *CIBSE Guide A*.

$$R_{sus\text{-}floor} = R_{si} + R_g + R_{t1} + (((1 / (R_{t1} + R_e)) + (1 / (R_{t2} + R_v)))^{-1}$$

Where, R_{si} = surface resistance = 0.14 $m^2.K.W^{-1}$
R_g = resistance of floor = 1 / 0.123, = 8.104 $m^2.K.W^{-1}$
R_{t1} = transform resistance 1[17] = 0.09 $m^2.K.W^{-1}$
R_{t2} = transform resistance 2 = 0.29 $m^2.K.W^{-1}$
R_e = resistance of the earth = (1 / 0.123) – 0.14, = 7.99 $m^2.K.W^{-1}$

$R_{sus\text{-}floor}$ = 11.03

$U_{sus\text{-}floor}$ = 1 / 10.82, = **0.093 $W.m^{-2}.K^{-1}$**

Use of Recycled Materials

As the Warmcel is made from recycled newspaper, its specification will ensure that 100 percent of the insulation material is from recycled sources. It is also proposed that the roof will be tiled in reused slates, ideally from the site itself. Therefore excluding the basement virtually all of the material used in the construction of the dwelling is from reused, recycled or renewable sources. The in-situ concrete foundations and slab of the basement floor, if included, would use recycled aggregate, ideally derived from the demolition of existing buildings on the site. The only problematic material might be the Thermalite, or equivalent, concrete block walls, for which a source that uses recycled aggregate may not be able to be determined. An alternative would be the use of prefabricated concrete panels to line the basement, which would be specified to use recycled aggregates; this would also increase the rate of construction.

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17 The transform resistances account for the radiative and convective resistances; these are taken from the *CIBSE Guide A*.

Use of Renewable Materials

Timber is inherently a renewable source; it would be a requirement of the specification of the dwelling that all of the timber which is not from a recycled source be from a certified renewable source; this will ensure compliance with the benchmark. This requirement for the source of materials was accounted for within the cost estimate produced by Davis Langdon Everest. However, the benchmark between the quantity of timber from a recycled source and from a renewable source is interrelated; the latter can be increased to account for a shortfall in the former to ensure the sustainability of the material. Therefore whilst it has not been feasible within the scope of this Study to ensure that 25 percent of the 26.2 tonnes of timber used within the dwelling would be from recycled sources, any that is not will be from a renewable resource.

Utilisation of Local Resources

Within the scope of the Drawn Study is has not been possible to establish suppliers for the materials from which the dwelling would be constructed, and therefore to establish if the benchmark of 45 kilometres could be achieved. The specific intention that wherever possible materials that arise from the clearance of the site would be reused would assist in complying with the benchmark. However, the use of timber frame to create the structure may have detrimental implications; whilst panels could be prefabricated locally, the timber would have to be transported from elsewhere in the United Kingdom. It would not be possible to find a timber source within the radius of 45 kilometres.

Water Consumption: Construction

The assessment against the benchmark is based on the quantity of water consumed in the construction of the structure of the dwelling on site. Because the basement is constructed from materials that would increase the use of water on site two scenarios are appraised, one with the basement included and one with it excluded. The quantity of water used in standard mixes of concrete and mortar were calculated. The total volume of mortar can be established by dividing the area of basement wall by the area of one block, to calculate the number of blocks; the area of mortar around one block is then multiplied by the depth of the block and the number of blocks to calculate the total volume. The area and depth of the slab can be used to derive the volume of concrete. The perimeter of the dwelling and the depth and width of the foundations can be used to derive their volume. In the scenario that excludes the basement, a 0.8 m wall below ground is included to account for the masonry wall on which the timber frame of the walls above ground will stand.

Scenario with basement:

Wall = 66.24 / (0.13 x 0.41) = 1,027 blocks

1,027 x (0.0054 x 0.25) = 1.386 m^3 mortar

1.386 x 0.4 = 0.555 m^3 water, = 554.6 litres

Slab = 46.4 x 0.25 = 11.6 m^3 concrete

(11.6 / 7) x 0.4 = 0.66 m^3 water, = 662.8 litres

Foundation = 27.6 x 0.6 x 0.3 = 4.97 m3 concrete

(4.97 / 7) x 0.4 = 0.28 m^3 water, = 283.8 litres

Total water = 554.6 + 662.8 + 283.8 = 1,501.2 litres

1,501.2 / 126.4 = 11.9 $l.m^{-2}$

Scenario excluding basement:

Wall = 19.8 / (0.13 x 4.1) = 372 blocks

372 x (0.0054 x 0.25) = 0.50 m^3 mortar

0.502 x 0.4 = 0.201 m^3 water, = 200.9 litres

Foundation = 27.6 x 0.6 x 0.3 = 4.97 m3 concrete

(4.97 / 7) x 0.4 = 0.28 m^3 water, = 283.8 litres

Total water = 200.9 + 283.8 = 484.7 litres

484.7 / 126.4 = 3.83 $l.m^{-2}$

Water Consumption: Inhabitation

The predicted water consumption of the dwelling was established from the table of individual sources of consumption in Annexe 3.37, refer to volume 3. The most significant reduction is achieved through the use of the composting toilet. This reduces that daily consumption of each inhabitant by almost one third in comparison to that of a typical dwelling. The consumption is summarised in the following table.

Function	Consumption ($l.p^{-1}.d^{-1}$)
Drinking and cooking	6.5
Personal hygiene (washing)	5
Personal hygiene (shower)	20
Laundry	5
Dish washing	1.8
Total	38.3

Predicted water consumption of the dwelling

Based on the maximum predicted occupancy of 6 inhabitants, the consumption of the whole dwelling would be 229.8 litres per day. The potential quantity of rainwater that is available to fulfil this demand can be determined from the annual average rainfall for the dwelling's location and the area of collection surfaces.[18] The annual rainfall in Manchester is 819 mm, established from meteorological data. This can be quantified by the following equation, established in the design of the assessment tool, refer to 9.7 in volume 1.

$$(0.9 \times \text{area of collecting surfaces} \times {}^{2}/_{3} \text{ annual rainfall}) / 365.25$$

$$= (0.9 \times 57.37 \times (0.66 \times 819)) / 365.25$$

$$= 77.16 \ l.d^{-1}$$

$$= 12.9 \ l.p^{-1}.d^{-1}$$

Therefore, the potable mains consumption is the shortfall between the predicted consumption and the water available from rainwater harvesting.

$$38.3 - 12.9 = \quad 25.4 \ l.p^{-1}.d^{-1}$$

[18] 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.

	Element	Replacements	Net Volume	Gross Volume	Material	Total Mat Volume	Density	Mass	Em En per unit mass	Embodied Energy
	Scenario including basement									
Foundations										
	Wall below gnd	1	0.6700	0.6700	Brick	0.6700	1750	1172.50	1.20	1407.0000
	Cavity fill	1	0.3350	0.3350	Fill	0.3350	500	167.50	0.01	1.6750
	Strip	1	3.3100	3.3100	Concrete	3.3100	2600	8606.00	0.20	1721.2000
									Foundations - Total	**3129.8750**
Basement										
	Walls	1	9.6140	9.6140	Concrete	9.6140	1200	11536.80	0.50	5768.4000
	Floor	1	10.2025	10.2025	Concrete	10.2025	2600	26526.50	0.20	5305.3000
	Membrane	1	0.2031	0.2031	Membrane	0.2031		0.00		0.0000
	Cavity fill	1	3.5420	3.5420	Fill	3.5420	500	1771.00	0.01	17.7100
									Basement - Total	**11091.4100**
	Scenario excluding basement									
Foundations										
	Wall below gnd	1	2.3900	2.3900	Brick	2.3900	1750	4182.50	1.20	5019.0000
	Cavity fill	1	1.1950	1.1950	Fill	1.1950	500	597.50	0.01	5.9750
	Strip	1	2.3900	2.3900	Concrete	2.3900	2600	6214.00	0.20	1242.8000
									Foundations - Total	**6267.7750**
Ground Floor										
First floor	Joists	1	0.7806	0.7806						
	Floor boards	1	0.7881	0.7881						
	Noggins	1	0.0520	0.0520						
	Stairs	2	0.0556	0.1112						
	Headers	1	1.1400	1.1400	Timber	2.8719	700	2010.35	0.10	201.0348
	Insulation	1	9.8758	9.8758	Cellulose Insul	9.8758	24	237.02	0.49	116.1394
	Membrane	1	0.0898	0.0898	Membrane	0.0898		0.00		0.0000
									Ground Floor - Total	**317.1742**
External Walls										
Ground floor - inner	Studs	1	0.4860	0.4860						
	Soles	1	0.1630	0.1630						
	Headers	1	0.4075	0.4075						
	Sheathing	1	0.8586	0.8586						
	Cills + Heads	1	0.0650	0.0650	Timber	1.9801	700	1386.07	0.10	138.6070
	Insulation	1	2.4160	2.4160	Cellulose Insul	2.4160	40	96.64	0.49	47.3536
	Finish	2	0.4293	0.8586	Plaster/P'bd	0.8586	600	515.16	0.50	257.5800
Ground floor - insul	Insulation	1	4.3752	4.3752	Cellulose Insul	4.3752	40	175.01	0.49	85.7539
Ground floor - outer	Studs	1	0.3645	0.3645						
	Soles	1	0.1670	0.1670						
	Headers	1	0.4175	0.4175						
	Sheathing	1	0.8934	0.8934						
	Cills + Heads	1	0.0650	0.0650						
	Battens	4	0.0677	0.2709						
	Weatherb'ding	4	0.7292	2.9168	Timber	5.0951	700	3566.54	0.10	356.6545
	Insulation	1	2.5865	2.5865	Cellulose Insul	2.5865	40	103.46	0.49	50.6954

	Element	Replacements	Net Volume	Gross Volume	Material	Total Mat Volume	Density	Mass	Em En per unit mass	Embodied Energy
First floor - inner	Studs	1	0.4760	0.4760						
	Soles	1	0.1640	0.1640						
	Headers	1	0.4100	0.4100						
	Sheathing	1	0.9798	0.9798						
	Cills + Heads	1	0.0800	0.0800	Timber	2.1098	700	1476.86	0.10	147.6860
	Insulation	1	2.7730	2.7730	Cellulose Insul	2.7730	40	110.92	0.49	54.3508
	Finish	2	0.4899	0.9798	Plaster/P'bd	0.9798	600	587.88	0.50	293.9400
First floor - insul	Insulation	1	4.9008	4.9008	Cellulose Insul	4.9008	40	196.03	0.49	96.0557
First floor - outer	Studs	1	0.4025	0.4025						
	Soles	1	0.1690	0.1690						
	Headers	1	0.4225	0.4225						
	Sheathing	1	1.0323	1.0323						
	Cills + Heads	1	0.0800	0.0800						
	Battens	4	0.0853	0.3411						
	Weatherb'ding	4	0.8234	3.2936	Timber	5.7410	700	4018.69	0.10	401.8692
	Insulation	1	3.0060	3.0060	Cellulose Insul	3.0060	40	120.24	0.49	58.9176
	Membrane	1	0.0688	0.0688	Membrane	0.0688		0.00		0.0000
Second floor - inner	Studs	1	0.4805	0.4805						
	Soles	1	0.2010	0.2010						
	Sheathing	1	1.3530	1.3530						
	Cills + Heads	1	0.0760	0.0760	Timber	2.1105	700	1477.35	0.10	147.7350
	Insulation	1	4.3860	4.3860	Cellulose Insul	4.3860	40	175.44	0.49	85.9656
	Finish	2	0.6333	1.2666	Plaster/P'bd	1.2666	600	759.96	0.50	379.9800
Second floor - insul	Insulation	1	5.2716	5.2716	Cellulose Insul	5.2716	40	210.86	0.49	103.3234
Second floor - outer	Studs	1	0.4825	0.4825						
	Soles	1	0.3045	0.3045						
	Sheathing	1	1.5015	1.5015						
	Cills + Heads	1	0.0760	0.0760						
	Battens	4	0.0789	0.3155						
	Weatherb'ding	4	0.2614	1.0456	Timber	3.7256	700	2607.93	0.10	260.7934
	Insulation	1	4.2555	4.2555	Cellulose Insul	4.2555	40	170.22	0.49	83.4078
	Membrane	1	0.1001	0.1001	Membrane	0.1001		0.00		0.0000
									External Walls - Total	**3050.6688**
Party Walls										
Ground floor	Studs	1	0.3915	0.3915						
	Soles	1	0.1320	0.1320						
	Headers	1	0.3300	0.3300						
	Sheathing	1	0.9570	0.9570	Timber	1.8105	700	1267.35	0.10	126.7350
	Insulation	1	1.7183	1.7183	Cellulose Insul	1.7183	40	68.73	0.49	33.6777
	Finish	5	0.5085	2.5425	Plaster/P'bd	2.5425	600	1525.50	0.50	762.7500
First floor	Studs	1	0.3915	0.3915						
	Soles	1	0.1320	0.1320						
	Headers	1	0.3300	0.3300						
	Sheathing	1	0.9570	0.9570	Timber	1.8105	700	1267.35	0.10	126.7350
	Insulation	1	1.7183	1.7183	Cellulose Insul	1.7183	40	68.73	0.49	33.6777

	Element	Replacements	Net Volume	Gross Volume	Material	Total Mat Volume	Density	Mass	Em En per unit mass	Embodied Energy
Second floor	Studs	1	0.5670	0.5670						
	Soles	1	0.1420	0.1420						
	Sheathing	1	1.3860	1.3860						
	Weatherb'ding	4	0.1408	0.5632	Timber	2.6582	700	1860.74	0.10	186.0740
	Insulation	1	1.7183	1.7183	Cellulose Insul	1.7183	40	68.73	0.49	33.6777
	Finish	5	0.5934	2.9670	Plaster/P'bd	2.9670	600	1780.20	0.50	890.1000
									Party Walls - Total	**2193.4271**
Windows										
	Glazing	2	0.4975	0.9950	Glass	0.9950	2500	2487.60	6.00	14925.6000
	Frame	2	0.3620	0.7240	Timber	0.7240	700	506.80	0.10	50.6800
									Windows - Total	**14976.2800**
Internal Floors										
First floor	Joists	1	0.7219	0.7219						
	Floor boards	1	0.8090	0.8090						
	Noggins	1	0.0520	0.0520						
	Stairs	2	0.1136	0.2271	Timber	1.8100	700	1267.00	0.10	126.6997
	Finish	5	0.6817	3.4083	Plaster/P'bd	3.4083	600	2044.95	0.50	1022.4750
Second floor	Joists	1	0.7844	0.7844						
	Floor boards	1	0.7110	0.7110						
	Noggins	1	0.0520	0.0520						
	Balcony (base)	1	0.1700	0.1700						
	Stairs	2	0.1136	0.2271	Timber	1.9445	700	1361.13	0.10	136.1133
	Insulation	1	3.1860	3.1860	Cellulose Insul	3.1860	24	76.46	0.49	37.4674
	Balcony (fin)	1	0.2040	0.2040	Ceramic	0.2040		0.00		0.0000
	Finish	2	0.6326	1.2651	Plaster/P'bd	1.2651	600	759.06	0.50	379.5300
									Internal Floors - Total	**1702.2853**
Roof										
	Joists	1	1.6484	1.6484						
	Battens	2	0.2586	0.5171						
	Sheathing	1	1.6524	1.6524	Timber	3.8179	700	2672.53	0.10	267.2533
	Insulation	1	26.4588	26.4588	Cellulose Insul	26.4588	24	635.01	0.49	311.1555
	Waterproofing	1	0.1377	0.1377						
	Membrane	1	0.1102	0.1102	Sheeting	0.2479		0.00		0.0000
	Tiling	2	1.0659	2.1318	Tiling	2.1318	1200	2558.16	0.50	1279.0800
	Intnl finish	2	0.7623	1.5246	Plaster/P'bd	1.5246	600	914.76	0.50	457.3800
									Roof - Total	**2314.8688**

Dwelling Total (with basement)	kWh	**38776.0**
	kWh.m-2	**306.7**
Dwelling Total (without basement)	kWh	**30822.5**
	kWh.m-2	**243.8**

SAP WORKSHEET (Version 9.60)

1. Overall dwelling dimensions

	Area (m²)			Average room height (m)		Volume (m³)	
Ground floor	44·89	(1a)	×	3·0	=	134·67	(1b)
First floor	44·68	(2a)	×	3·0	=	134·04	(2b)
Second floor	36·86	(3a)	×	4·2	=	154·81	(3b)
Third and other floors		(4a)	×		=		(4b)
Total floor area (1a) + (2a) + (3a) + (4a) =	126·43	(5)					
Dwelling volume	(1b) + (2b) + (3b) + (4b)				=	423·52	(6)

2. Ventilation rate

			m³ per hour			Air changes per hour	
Number of chimneys	0	× 40 =	0	(7)			
Number of flues	0	× 20 =	0	(8)			
Number of fans and passive vents	0	× 10 =	0	(9)			
Infiltration due to chimneys, fans and flues	= (7) + (8) + (9)	=	0		÷ (6) =	0	(10)

If a pressurisation test has been carried out, proceed to box (19)

Number of storeys				(11)
Additional infiltration	[(11) – 1] × 0.1 =			(12)
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction*				(13)
If suspended wooden floor, *enter 0.2 (unsealed) or 0.1 (sealed)*				(14)
If no draught lobby, enter 0.05				(15)
Percentage of windows and doors draughtstripped *Enter 100 in box (16) for new dwellings which are to comply with Building Regulations*				(16)
Window infiltration	0.25 – [0.2 × (16) ÷ 100]	=		(17)
Infiltration rate	(10) + (12) + (13) + (14) + (15) + (17)	=		(18)
If pressurisation test done, then [measured L_{50} ÷ 20] + (10), otherwise (19) = (18)			0·0085	(19)
Number of sides on which sheltered *(Enter 2 in box (20) for new dwellings where location is not shown)*			2	(20)
Shelter factor	1 – [0.075 × (20)]	=	0·85	(21)
If mechanical ventilation with heat recovery, effective air change rate	= [(19) × (21)] + 0.17	=	0·177	(22)
(If no heat recovery, add 0.33 air changes per hour to value in box (22))				
If natural ventilation, then air change rate	= (19) × (21)	=		(23)
	if (23) ≥ 1, then (24) = (23)			
	otherwise (24) = 0.5 + [(23)² × 0.5]	=		(24)
Effective air change rate – enter (22) or (24) in box (25)			0·177	(25)

3. Heat losses and heat loss parameters

ELEMENT		Area (m²)		U-value (W/m²K)		A × U	
Doors		4.0	×	0.55	=	2.28	(26)
Windows (type 1)*	0.9 ×	37.12	×	0.8	=	26.73	(27)
Windows (type 2)*	0.9 ×		×		=		(28)
Rooflights*	0.9 ×		×		=		(29)
Ground floor		44.89	×	0.10	=	5.84	(30)
Walls (type 1) *excluding windows and doors*		129.2	×	0.12	=	15.50	(31)
Walls (type 2) *excluding windows and doors*			×		=		(32)
Roof (type 1) *excluding rooflights*		55.08	×	0.08	=	4.41	(33)
Roof (type 2) *excluding rooflights*			×		=		(34)
Other			×		=		(35)

**the factor 0.9 takes into account the normal use of curtains*

Ventilation heat loss	= [redacted] × 0.33 × [redacted]	=	24.74	(36)
Heat loss coefficient, W/K	= [redacted] + [redacted] + ... + [redacted] + [redacted]	=	79.50	(37)
Heat loss parameter (HLP), W/m²K	= [redacted] ÷ [redacted]	=	0.67	(38)

4. Water-heating energy requirements

				GJ/year	
Hot water energy requirement (Table 1, column (a))				4.47	(39)
Distribution loss (Table 1, column (b)), however *If instantaneous water heating at point of use, enter '0' in boxes (40) to (43) and (48)* *For community heating use Table 1(b) whether or not hot water tank present*				0.78	(40)
Hot water storage volume (litres) *If no stored water enter '0'* *If heated by community heating and no tank, enter 110 litres in box (41)*		189	(41)		
Hot water storage loss factor (Table 2) *If community heating and no tank, enter 0.0079*		0.0078	(42)		
Energy lost from hot water storage, GJ/year	[redacted] × [redacted]		=	1.44	(43)
Area of solar panel, m² *If no solar panel, enter '0' in boxes (44) to (47) and go to (48)*		0	(44)		
Solar energy available	= 1.3 × [redacted] =	0	(45)		
Load ratio	= [redacted] ÷ [redacted] =	0	(46)		
Solar input	= [[redacted] × [redacted]] ÷ [1 + [redacted]] =	0	(47)		
Primary circuit loss (Table 3)				0.5	(48)
Output from water heater, GJ/year	= [redacted] + [redacted] + [redacted] + [redacted] − [redacted]		=	7.15	(49)
Efficiency of water heater, % *(Use value from Table 4a or 4b adjusted, where appropriate, by the amount shown in the 'efficiency adjustment' column of Table 4c, and by the 'efficiency adjustment' column of Table 4e.)*		250	(50)		
Energy required for water heating	= [[redacted] × 100] ÷ [redacted]		=	2.86	(51)
Heat gains from water heating	= [0.25 × [redacted]] + 0.8 [[redacted] + [redacted] + [redacted]]		=	3.28	(52)

5. Internal gains

			Watts	
Lights, appliances, cooking and metabolic (Table 5)			719	(53)
Additional gains from Table 5 (Note) if heated by system other than community heating scheme			25	(53a)
Water heating	= 31.71 × [illegible]	=	104·01	(54)
Total internal gains	= [illegible] + [illegible] + [illegible]	=	844·01	(55)

6. Solar gains

ELEMENT	Area (m2)		Flux (Table 6)		Gains (W)	
North		×		=		(56)
North east		×		=		(57)
East		×		=		(58)
South east	35	×	23	=	805·0	(59)
South		×		=		(60)
South west		×		=		(61)
West		×		=		(62)
North west	2·04	×	12	=	24·48	(63)
Rooflights		×		=		(64)
	[illegible] + ... + [illegible]			=	829·48	(64a)

Solar access factor (Table 6a), for new dwellings where overshading is not known, enter '1'			1	(65)
Solar gains (standard location)	[illegible] × [illegible]	=	829·48	(66)
Total gains, W	[illegible] + [illegible]	=	1673·49	(67)
Gain/loss ratio (GLR)	(67) ÷ [illegible]	=	21·05	(68)
Utilisation factor (Table 7)			0·58	(69)
Useful gains, W	(67) × (69)	=	970·62	(70)

7. Mean internal temperature

			°C	
Mean internal temperature of the living area (Table 8)			18·88	(71)
Temperature adjustment from Table 4e, where appropriate				(71a)
Adjustment for gains	= {[(70) ÷ [illegible]] − 4.0} × 0.2 × R	=	1·64	(72)
R is obtained from the 'responsiveness' column of Table 4a or Table 4d				
Adjusted living room temperature	(70) + (71a) + (72)	=	20·52	(73)
Temperature difference between zones (Table 9)			0·40	(74)
Living area fraction (0 to 1.0)	living room area ÷ [illegible]	=	0·11	(75)
Rest-of-house fraction	= 1 − [illegible]	=	0·89	(76)
Mean internal temperature	= [illegible] − [[illegible] × [illegible]]	=	20·16	(77)

8. Degree days

Temperature rise from gains	(70) ÷ [illegible]	=	12·21	(78)
Base temperature	(77) − (78)	=	7·95	(79)
Degree days (use box (79) and Table 10)		=	620	(80)

9. Space-heating requirement

			GJ/year	
Energy requirement (useful)	= 0.000 086 4 × [redacted] × [redacted]	=	4·26	(81)

Conventional heating systems:
Note: when space and water heating is provided by community heating, use the alternative SAP worksheet (on next page) from this point

Fraction of heat from secondary system *(Use value from Table 11)*			0	(82)
Efficiency of main heating system, % *(Use value from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c, and by the 'efficiency adjustment' column of Table 4e)*			240	(83)
Efficiency of secondary heating system *(Use value obtained from Table 4a)*				(84)
Space-heating fuel (main)	[1 − [redacted]] × [redacted] × 100 ÷ [redacted]	=	1·77	(85)
Space-heating fuel (secondary)	[redacted] × [redacted]] × 100 ÷ [redacted]	=		(86)
Electricity for pumps and fans:				
0.47 GJ for each central heating pump			1·69	(87a)
0.16 GJ for each boiler with a fan-assisted flue				(87b)
For warm-air heating system fans,	*0.002 GJ* × (6)	=		(87c)
For dwellings with whole-house mechanical ventilation,	*0.004 GJ* × (6)	=		(87d)
	(87a) + (87b) + (87c) + (87d)	=		(87)

10. Fuel costs

		GJ/year	×	Fuel price (Table 12)	=	£/year	
Space heating – main system	=	(85)	×		=		(88)
Space heating – secondary system	=	(86)	×		=		(89)

Water heating

If off-peak electric water heating:

On-peak percentage (Table 13)			(90)
Off-peak percentage	= 100 − (90) =		(91)

		×	Fuel price	=		
On-peak cost	= [(61) × (90)] ÷ 100	×		=		(92)
Off-peak cost	= [(61) × (91)] ÷ 100	×		=		(93)
Otherwise, water-heating costs	= (61)	×		=		(94)
Pump and fan energy cost	= (87)	×		=		(95)
Additional standing charges (Table 12)						(96)
Total heating	[redacted] + [redacted] + [redacted] + [redacted] + [redacted] + [redacted] + [redacted]			=		(97)

11. SAP rating (conventional heating)

Energy cost deflator (Table 12)				(98)
Energy cost factor (ECF)	= {[[redacted] × [redacted]] − 40.0} ÷ [redacted]	=		(99)
SAP rating (Table 14)				(100)