COMFORT AND COST

Low carbon timber frame in a changing climate

Contents

5. Appendices

With reference to:
UKTFA Zero Carbon Project, Energy
for Sustainable Development, 2009

Maintaining Thermal Comfort in Light
Weight Timber Residential Structures,
Buro Happold, 2009

www.woodforgood.com

www.timber-frame.org

Introduction

Residential buildings are responsible for 15% of the UK's CO_2 emissions, mainly from space and water heating.[1] Energy efficiency is therefore at the heart of the Government's Code for Sustainable Homes, with its target of ensuring all new homes are 'zero carbon' by 2016, backed by more demanding energy-efficiency targets to be introduced in successive revisions to the Building Regulations.

The UK needs more energy-efficient homes and buildings to meet these demands to reduce CO_2 emissions and help mitigate the effects of climate change. But the materials and the processes of construction itself demand energy and result in CO_2 emissions. Currently this 'embodied carbon' phase accounts for around a fifth of the whole life 'carbon cost' of a building. Increasing energy-efficiency is likely to shift that balance, so that the embodied phase will account for the greater part.

Here wood has a significant advantage, because the carbon sink effect of the forest means wood has negative embodied carbon dioxide – the more wood you use in a building, the lower its carbon footprint.[2]

Timber frame is widely accepted as one of the most sustainable construction methods available. Wood from sustainably managed forests is naturally renewable. As well as reducing the embodied carbon dioxide of a building by its substitution for more energy intensive materials, it also delivers good thermal performance in use, and is ideally suited for off-site construction, the best solution for accuracy, efficiency, air-tightness and low waste.

But just how cost-effective is timber frame when it comes to building more energy-efficient homes? And how comfortable will timber frame homes be in the warmer climate we are expecting towards the end of the century?

This publication aims to answer these questions, while providing guidance on how timber frame can be used to achieve Code for Sustainable Homes ratings, how thermal comfort can be optimised in timber frame construction, and what other aspects should be considered when designing-in thermal efficiency.

[1] Defra, Source of UK CO_2 emissions 2005 [2] Timber legally sourced from sustainably managed forests

1. Zero Carbon Homes:

building methods and costs

Sigma House courtesy of Stewart Milne

Key Findings

Timber frame dwellings generally show a lower additional cost than a typical masonry dwelling to achieve compliance with a HLP of 1.3, 1.1 and 0.8. The cost differential is in the order of 2.2% to 5.2%, depending on the dwelling type.

The environmental benefits of timber mean specifications fall largely in the ‘A+’ or ‘A’ rated category in the Material Credits section of the Code for Sustainable Homes.

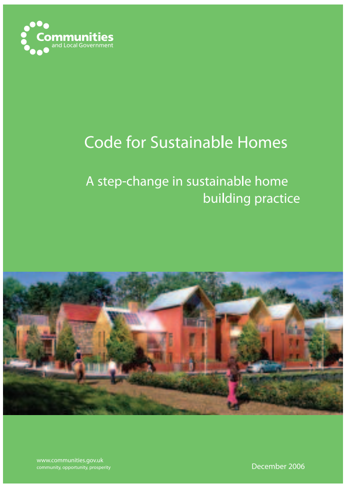
Similarly, certified timber scores the highest responsible sourcing credits, compared with masonry’s mid-range credits.

The overall carbon dioxide emissions for timber construction (the embodied carbon dioxide) are up to six times lower than for masonry.

The additional costs of achieving Code for Sustainable Homes compliance are lower for timber frame than masonry, particularly for detached and end-of-terrace dwellings.

Introduction

The government’s determination to improve the sustainability and energy efficiency of UK homes led to the introduction of the Code for Sustainable Homes (CSH) in December 2006. Code Level 3 is already mandatory on developments on government owned land, while the government plans to make Code Level 6, with its zero carbon requirement, mandatory for all new homes by 2016. This will involve progressive changes to the Building Regulations: against a 2006 Part L baseline, a 25% improvement in carbon performance will be required by 2010, followed by a 44% improvement by 2013.



Communities
and Local Government

Code for Sustainable Homes

A step-change in sustainable home
building practice

www.communities.gov.uk
community, opportunity, prosperity

December 2006

Achieving higher Code levels inevitably adds to construction costs. This study aims to provide a comparative analysis of the environmental performance and cost implications of timber frame versus masonry construction.

Four dwelling types have been selected to cover a cross-section of housing variables such as size, proportion of exposed external elements, occupation levels, etc.

In general, the key CSH issues affected by construction type are energy consumption within dwellings (a function of the fabric-related energy efficiency measures), plus the environmental rating and sourcing of building materials.

Fabric energy efficiency measures can deliver up to a 33% reduction in energy consumption (as expressed in terms of the ‘Dwelling Emission Rate’) for large detached houses and up to 20% for apartments.

New Hall Harlow courtesy of PCKO Architects and Tim Crocker

The comparative costs of achieving lower Heat Loss Parameters

The timber frame dwellings generally show a lower additional cost to achieve compliance with a Heat Loss Parameter[1] (HLP) of 1.3, 1.1 and 0.8 than a typical masonry dwelling. Typically, the cost differential has been assumed to be in the order of 2.2% to 5.2%, depending on the dwelling type:

- The comparative difference is widest at HLP 1.3, with timber showing an additional cost ranging from 0.3% to 4.4%, compared with masonry's 1.2% to 8.3%.
- At HLP 1.1 the comparative cost increases are 1.4% to 9.7% for timber and 2.3% to 13% for masonry.
- At HLP 0.8 the comparative cost increases are 7.9% to 15.5% for timber and 8.8% to 19.9% for masonry.

Generally, the additional costs are lower for flats and mid-terrace units than end-terrace and detached units, as would be expected given their lower exposed wall-to-floor ratios.

Ecopark Thamesmead courtesy of Gallions Housing Association and PRP Architects

Heat Loss Parameters are affected by:

- Exposed surface area. E.g. mid-floor flats have a lower HLP than a detached house of similar specification.
- U-values. The lower the U-values of building elements the lower the HLP. However, as better U-values reduce the proportion of fabric heat loss, ventilation losses become more significant.
- Thermal bridging. As U-values improve, the proportion of heat loss due to thermal bridging becomes more significant. Ensuring insulation continuity and adopting accredited construction details reduces the heat loss factor (y-value) associated with non-repeating thermal bridging for exposed building elements from 0.15 to 0.08. Even where these details are adopted, the heat loss due to thermal bridging can be as much as 50% of the total fabric heat loss for large highly insulated dwellings.
- Air permeability. Reducing air permeability helps to lower the overall ventilation losses and HLP, but when the dwelling is naturally ventilated the savings are limited by the fresh air requirements and heat losses through extract fans for wet areas. In such instances, mechanical ventilation with heat recovery may be required to get the HLP below 0.8. This is especially true for detached houses with large exposed surface areas that also have a significant proportion of fabric losses. When retaining natural ventilation, there is little value in achieving an air-tightness better than 5m^3/m^2/hr.
- Infiltration rate. This is calculated as a function of the air permeability and the number of chimneys, flue and fans and is further affected by how exposed or sheltered the dwelling is. Flats and mid-terrace houses have lower infiltration rates than detached houses as they tend to be sheltered on at least two sides, which has the affect of reducing the infiltration rate by as much as 15%.

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[1] Heat Loss Parameter (HLP) is an indication of the heat loss per unit floor area of the dwelling taking into account both fabric and ventilation losses.

Airtightness

Much depends on the quality of workmanship and how well the dry-lining and service penetrations are sealed, but in general, it is easier to make a dwelling airtight using timber frame than masonry, as it is ideally suited to pre-fabricated construction in controlled factory conditions.

This is partly due to the use of the impermeable vapour barrier as the air barrier in timber frame construction, and also because the edges of the plasterboard can be sealed directly to the timber framing to form an air barrier. Masonry external walls, especially those built from lightweight concrete blocks, have varying degrees of porosity, and therefore varying air permeability characteristics. Blockwork is unlikely to provide an adequate air barrier on its own and unfinished mortar joints also provide air leakage routes. Irrespective of construction type, continuity of the air barrier is essential to achieving performance standards.

Suspended timber floors are likely to have gaps around the boards at the junctions with internal and external walls and around service pipes. This is equally true of other forms of suspended floors such as beam and block flooring, especially where the screed is not laid properly. Large area boards and tongue and groove edges can reduce air leakage, subject to all gaps and holes being sealed before floor coverings are laid.

See Appendix 1 for advice on the measures to be taken to ensure good air-tightness and indicative detailing.

Re Thinking Education School Courtesy of White Design and Wilmott Dixon

Thermal bridging

Timber has a low coefficient of thermal conductivity; requiring less insulation than other materials, such as steel frame, to achieve the same U-value.
In masonry construction, mortar joints contribute to thermal bridging; the overall impact can be significant where lightweight blocks with low thermal conductivity are specified. For cavity walls, the cross-sectional area for the ties, and therefore the thermal bridging, increases with cavity width. However, the main concern for both timber and masonry construction is no-repeating thermal bridges, which can be addressed through appropriate detailing.

Timber Frame Systems

Open-panel systems rely on good workmanship and site supervision to deliver the required performance standards for heat loss, air-tightness and acoustics. Closed-panel systems can provide a higher degree of consistency. Apart from the standard product, some manufacturers also offer the option of upgraded bespoke products to achieve a specified thermal performance.

In broad terms, the cost of timber systems ranges from £130/m^2 to £190/m^2 for closed-panel systems.

See Appendix 2 for performance details for an indicative range of timber frame/panellised systems, as well as an indication of the typical costs for each system, on a £/m^2 of floor area basis.

Dwelling Emission Rate

A number of scenarios was explored to achieve compliance with the range of carbon dioxide reduction targets for all four dwelling types.

The first point to note is that the sizing, and therefore the costs, of the renewable energy technologies at each Code level is the same regardless of construction type.

The second is that, although the sizing, and therefore the capital cost, of any renewable energy technology reduces as a dwelling's HLP increases, this reduction in cost is generally not sufficient to offset the comparable increase in fabric cost.

Depending upon the level of energy efficiency measures incorporated, the net additional cost for delivering the amount of renewable energy required over and above the base cost of each dwelling is shown in the following table.

Net additional cost for the amount of renewable energy required

Code level	**3**	**4**	**5**	**6**
	Timber	Timber	Timber	Timber
Detached	0 to 4.5%	2.2 to 8.2%	11.0 to 21.8%	18.3 to 26.4%
End terrace	0 to 6.8%	3.0 to 11.0%	12.0 to 25.2%	21.0 to 36.2%
Mid-terrace	1.9 to 7.7%	4.9 to 12.7%	13.0 to 26.1%	22.9 to 39.5%
Flat	0.7 to 6.2%	2.9 to 10.0%	10.1 to 20.1%	16.9 to 30.2%

See Appendix 3 for an assessment of renewable energy technologies, strategies and costs to reach different Code levels.

Code for Sustainable Homes: HLP and Code 6 credits

Credits are awarded based on the Heat Loss Parameter (HLP) of the dwellings calculated using SAP 2005 methodology. HLP is an indication of the heat lost through a unit area of the building fabric and is a function of the thermal performance and air tightness of the fabric as well as its exposed surface area. For Code Level 6, the HLP is required to be less then 0.8 W/m^{2}K, the maximum stipulated for a zero carbon dwelling.

Performance requirements HLP	Weighted score	Mandatory levels
<1.3	1.3	
<1.1	2.5	
<0.8	2.5	Code Level 6

See Appendix 4 for guidance on the fabric specifications and ventilation systems required to achieve the above performance.

Code for Sustainable Homes: Materials credits

For most building elements, the environmental benefits of timber are clear, with timber specifications largely falling into the ‘A+’ or ‘A’ rated category.

Although the ratings for timber framed external walls depend on the type of external cladding, the commonly used specifications are again rated at the higher end of the scale, with an ‘A+’ rating for timber frame walls with softwood weatherboarding. Masonry external walls are also mainly ‘A+’ or ‘A’ rated.

However, for internal party walls and partitions, timber frame is rated ‘A+’, while masonry walls are rated ‘A’ or worse.

Hardwood or treated softwood domestic windows are rated ‘A+’ or ‘A’ depending on the type of paint used. Most high performance timber windows use water-based paints or stains and therefore rate ‘A+’. Domestic PVC-U windows are rated ‘A’, while other window types are rated ‘B’ or worse.

The maximum achievable score is 15 credits and the credit scoring system is indicated below. Credits are only awarded in multiples of whole numbers rounded down to the lower credit value (that is, 1.5 credits are rounded down to 1 credit).

With regard to responsible sourcing of materials, timber certified under Tier 1 schemes (FSC, PEFC, CSA, SFI) scores the highest credits. The supply chain for certified timber is now well established and a number of suppliers offer certified products at little or no cost premium.

In general, timber frame buildings with timber certified under Tier 1 schemes will score the highest credits. In comparison, masonry buildings are only likely to score mid-range credits even where relevant EMS certification is available at both process and extraction stage for all building materials. Even this may prove onerous both in terms of the paperwork involved and the limited number of suppliers offering certification that covers the products’ life cycle.

Green Guide Rating	Credits	Weighted Score
A+	3	0.9
A	2	0.6
B	1	0.3
C	0.5	
D	0.25	
E	0	

See Appendix 5 for further information on Materials credits and Responsible Sourcing.

Embodied CO_2

A comparison of the cradle-to-gate greenhouse gas (GHG) emissions associated with each of the four typical dwelling types shows those using masonry and concrete-intensive construction have significantly higher emissions than timber-intensive build types.

House type	Timber t CO_2 e	Concrete t CO_2 e
End-of-terrace house	4.0	21
Mid-terrace house	4.8	18
Detached house	4.96	32
Flat*	0.7	20

* Average figure for a dwelling based on a 3-storey block of flats

The results, categorised by construction and building type, are summarised in the following table. The large amounts of timber used in the timber-intensive construction create a carbon store which ultimately results in up to a sixfold reduction in the overall emissions for this type of construction compared to the masonry alternative.

Timber construction replaces many high emissions materials with wood, which has a negative cradle-to-gate emissions factor (even allowing for transport). This is because growing trees sequester CO_2 from the atmosphere and store it. When these trees are turned into useful building products and used in a building, the CO_2 is locked up and stored.

It should be noted that these emissions reductions resulting from the use of timber in construction will only be achieved if the timber is taken from a sustainably managed source.

When a cradle-to-grave scenario is considered, a timber product would release the majority of the CO_2 locked up within it. This would result in close to zero emissions from timber products which could be further improved if the waste timber is then used for energy production, displacing fossil fuel use. A comparison between the two building types would still result in much lower emissions from timber intensive construction compared to concrete and masonry intensive construction.

See Appendix 6 for a detailed breakdown of carbon dioxide emissions by construction and building type.

The cost of achieving Code for Sustainable Homes compliance

Although there are many different combinations of ways to achieve compliance, the suggested strategy is based on prioritising solutions that are both technically well-established and cost-effective. This may, however, vary depending on the scale of project and local planning and regulatory requirements.

Based on the modelling of generic timber framed or traditionally constructed dwelling types, the indicative additional costs associated with achieving Code compliance over and above a Part L 2006 compliant building fall into the following ranges:

Code level	**3**	**4**	**5**	**6**
Timber	5.6 to 18.6%	8.4 to 24.2%	17.3 to 40.6%	33.4 to 58.3%
Masonry	7.0 to 19.7%	10.7 to 29.9%	18.7 to 46.3%	34.6 to 61.5%

The number of permutations in the credits available to achieve Code level compliance, together with the differences associated with the various dwelling types modelled, generate quite wide bands of likely cost. However the analysis shows a significant increase in costs to achieve Code Levels 5/6 from Code Levels 3/4.

Generally, the figures at the lower end of each range relate to apartment developments and mid-terrace units, and assume that the lowest cost solution applicable to each credit area can be used. The most cost significant credits are likely to be those related to energy efficiency (building fabric) and energy generation (LZC technologies), with the costs for achieving water credits increasing significantly at Code Levels 5 and 6.

The sizing of renewable energy technologies at each Code Level appears to be determined by the dwelling's Heat Loss Parameter rather than by the construction type. In the main, the potential reduction in capital cost associated with the scaling down of renewable energy technologies as the HLP increases, is not generally sufficient to offset the comparable increase in fabric cost as the HLP increases.

Overall, the percentage cost uplifts to achieve Code compliance for a Part L compliant timber frame building are slightly lower than for a masonry building.

Summary of cost for compliance with relevant CSH target for each dwelling type

Code level	**3**		**4**		**5**		**6**	
	Timber	Masonry	Timber	Masonry	Timber	Masonry	Timber	Masonry
Detached	£8,655 - £11,835	£12,352 - £15,532	£11,933 - £24,008	£16,308 - £28,216	£24,433 - £40,248	£27,932 - £43,640	£40,988 - £53,918	£44,380 - £57,310
End terrace	£5,756 - £10,800	£6,538 - £13,290	£8,214 - £17,341	£9,614 - £19,514	£18,454 - £30,881	£19,038 - £32,238	£31,601 - £42,751	£32,958 - £44,108
Mid-terrace	£5,323 - £12,245	£6,157- £12,956	£7,781 - £13,853	£16,308 - £28,216	£24,433 - £40,248	£27,932 - £43,640	£40,988 - £53,918	£44,380 - £57,310
Flat	£4,287 - £14,093	£5,175- £14,472	£6,387 - £15,568	£7,851 - £16,523	£13,099 - £26,306	£13,747 - £25,944	£25,350 - £35,500	£25,489 - £35,639

Construction Waste Management

There is a mandatory requirement for construction projects in England over £300,000 to produce and implement a 'Site Waste Management Plan' (SWMP) across all Code levels. This will require setting targets to promote resource efficiency and the monitoring of construction waste generated on site.

Offsite timber frame construction can reduce waste through design, material procurement, manufacturing and onsite installation to levels under 2% of the material used.[1] The use of timber frame construction components can potentially reduce the amount of waste generated on site by between 20% and 40% depending on the level of offsite fabrication of the walls and floors.[2] The benchmark figure produced by BRE for residential developments is 14.9 kg/m^2 of floor area. However, this credit rewards the setting up of on-site procedures for waste minimisation and recycling rather than absolute targets, and is therefore independent of the construction technology used.

Whole Life Costs

The report suggests that for a well designed and constructed dwelling, the whole life cost implications for the structural and thermal insulation solutions within either a timber frame or masonry construction should not be significantly different. The major services option incorporated into a development to meet the required carbon or water use reduction targets, however, could have a significant impact over, say, a 30 year period.

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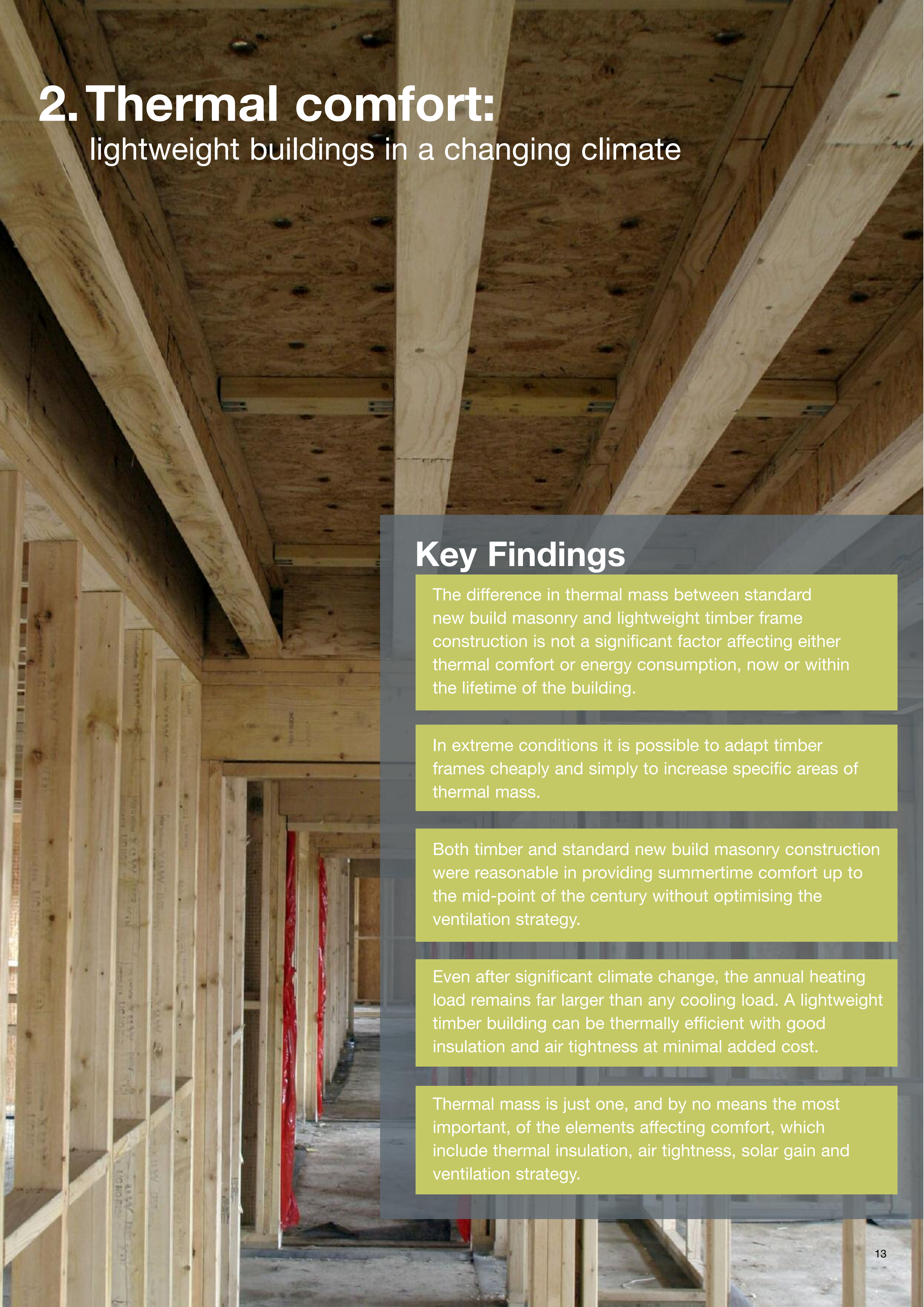
[1] WAS 003-003: Offsite Construction Case Study, WRAP (www. wrap.org.uk) [2] Current Practices and Future Potential in Modern Methods of Construction – Final report published,



2. Thermal comfort:

lightweight buildings in a changing climate

Key Findings

The difference in thermal mass between standard new build masonry and lightweight timber frame construction is not a significant factor affecting either thermal comfort or energy consumption, now or within the lifetime of the building.

In extreme conditions it is possible to adapt timber frames cheaply and simply to increase specific areas of thermal mass.

Both timber and standard new build masonry construction were reasonable in providing summertime comfort up to the mid-point of the century without optimising the ventilation strategy.

Even after significant climate change, the annual heating load remains far larger than any cooling load. A lightweight timber building can be thermally efficient with good insulation and air tightness at minimal added cost.

Thermal mass is just one, and by no means the most important, of the elements affecting comfort, which include thermal insulation, air tightness, solar gain and ventilation strategy.

Introduction

Lightweight timber structures are one of the most sustainable means of construction, using a low embodied energy material that can be supplied from a naturally renewable sustainable source.

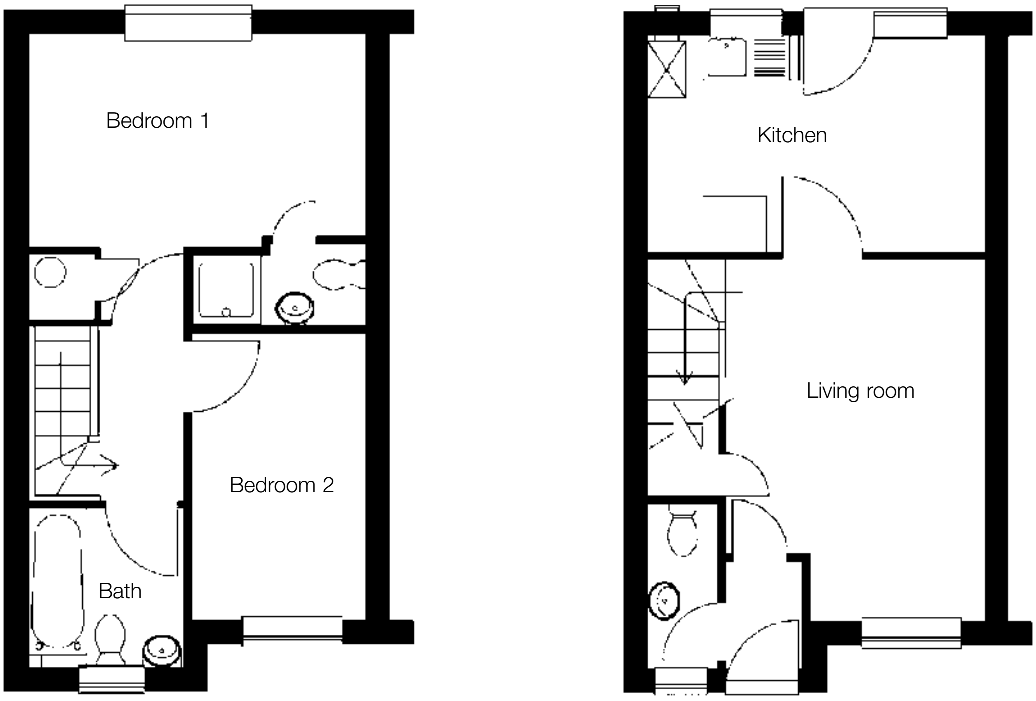
Embodied energy, and embodied carbon dioxide emissions, will become an increasingly important element of a dwelling's lifetime energy use as the operational energy consumption reduces due to factors such as the improved thermal insulation performance required by building regulations.

Timber is also light, strong, easy to transport and eminently suitable for reuse or recycling. It is now accepted that, because of rising levels of greenhouse gases, a degree of climate change is likely over the next 50 to 100 years (the lifetime of a house built today). Whilst the exact level of change is difficult to predict, the consensus is that parts of the UK may well experience summer temperatures similar to those common in southern Europe today.

The purpose of this report is to analyse the differences between current timber and masonry residential construction types to assess the role of thermal mass, taking into account actual occupancy and construction practices. The report looks at how expected future temperatures are likely to affect the comfort levels of housing, and also at the effect of incorporating additional thermal mass into lightweight timber construction.

The report considers a typical semi-detached dwelling and examines the effect of thermal mass on comfort initially through looking at two common construction methods: lightweight timber frame and standard new build masonry construction. Three further variants to the timber frame were then analysed to show the effects of adding thermal mass to a lightweight structure through a tiled floor, or double plasterboarding the walls, or through applying double cementboard to the walls.

Typical semi-detached dwelling used for study



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First Floor	
Bedroom 1	3785mm x 3700mm max.
Bedroom 2	3630mm x 2209mm
Bathroom	2025mm x 1960mm

Ground Floor	
Lounge	4705mm x 3319mm max.
Kitchen	4307mm x 2755mm

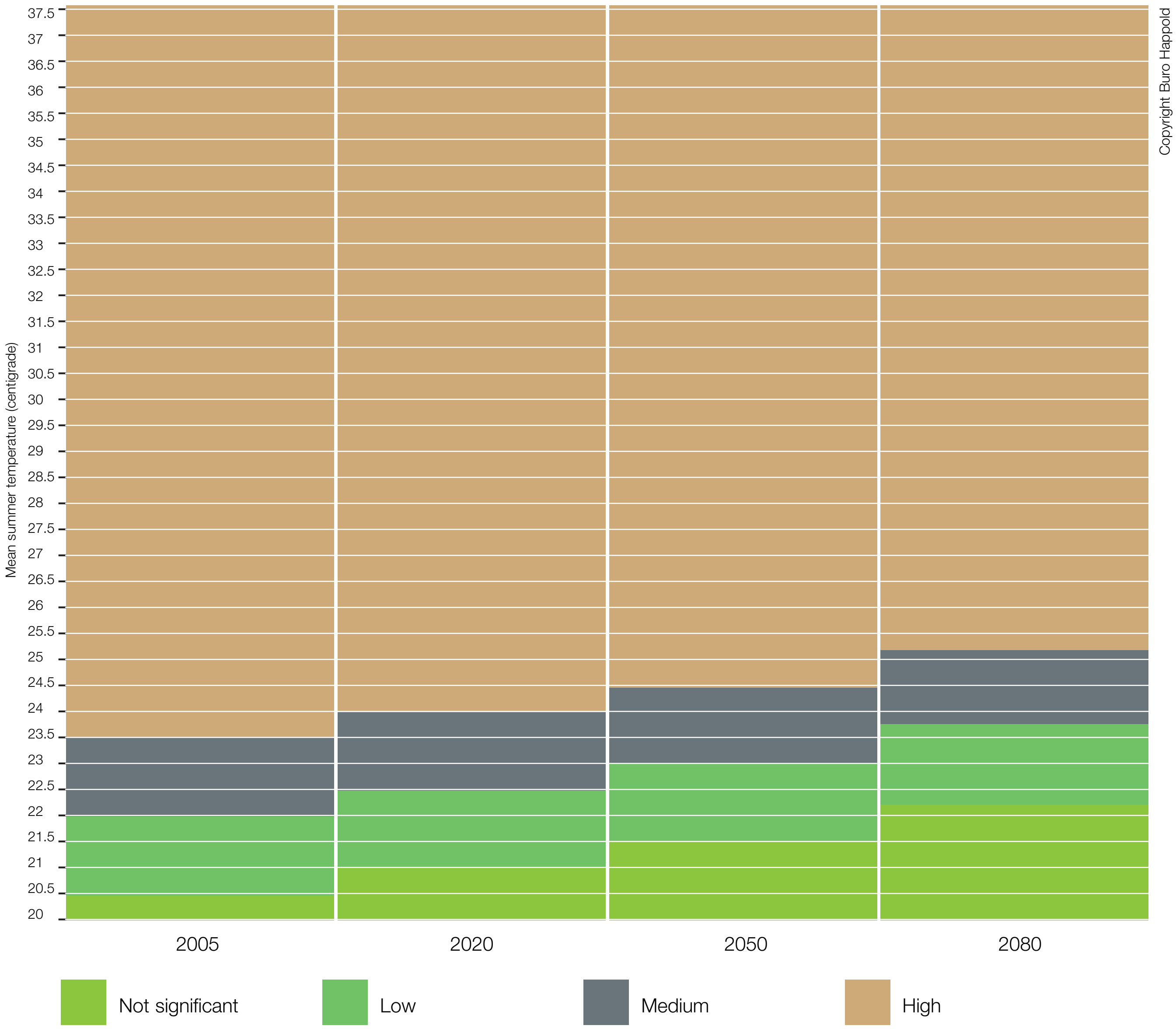
Buildings with high thermal mass are likely to be less well suited to occupants who lead a busy working life, where speed of warming and cooling is more important than maintaining a constant temperature. As the majority of houses in the UK are occupied by working people, a building is unlikely to be occupied all day (71% of modern houses have one or more people in employment). To reflect this, two occupancy patterns have been simulated:

- All Day Occupancy; where the house was assumed to be occupied by a family of two adults and one child. During the week one adult is assumed to be at home with the child during the day whilst the other adult is assumed to be out of the house at work.

- Evening Only Occupancy; where the house was assumed to be occupied by two adults who both work during the week.

SAP (Standard Assessment Procedure) methods for comfort criteria and Building Regulations Part L, Criterion 3 which defines the level of overheating risk, have been used to assess the results of the thermal modelling.

SAP comfort criteria



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The Code for Sustainable Homes has already set a range of energy related and thermal envelope standards for dwellings which go right up the scale to zero carbon operation and therefore will require dwellings to be better insulated and more energy efficient. For this report, however, the modelling looked at buildings constructed to current good practice (i.e. current Building Regulations).

Thermal mass

The UK government is currently focused on reducing energy consumption as a way of reducing carbon emissions and helping to curb the effect we are having on climate change. This is driving the market for low energy, thermally efficient, highly insulated buildings that incorporate sustainable technologies.

There is also a shift in emphasis towards achieving comfort through passive approaches which inherently reduce energy consumption. Passive design involves using the building materials and form of the building to achieve thermal comfort whilst using as little energy as possible. Thermal comfort therefore plays an important role in reducing energy consumption.

One way that can be used to improve thermal comfort passively is to increase the thermal mass of a building. Thermal mass is the capacity of a material to store heat (for a detailed definition see Appendix 7). Materials with high thermal mass tend to be dense and have low thermal conductivity, such as brick, concrete, earth or stone. These materials store and release heat slowly to the adjacent space.

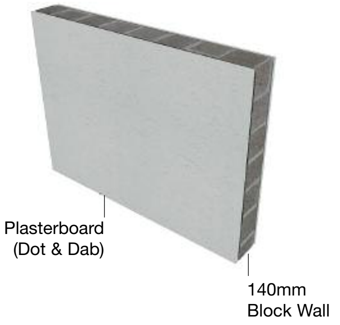
Current building practice means there is little difference in the effective thermal mass of a timber frame and a brick and block dwelling. Although timber frame buildings are more lightweight than masonry buildings, with low thermal mass in the timber frame and plasterboarded stud partitions, the potential benefits of the thermal mass within the concrete floor and brick and block external walls of a standard new-build masonry house are reduced by the ‘dot & dab’ method of fixing plasterboard to the inside of the walls. This creates an airgap between the plasterboard and blockwork, reducing the thermal conductivity through the element.

Thermal mass needs to be exposed to a space to have the most beneficial influence on summer comfort. The exposed surface is able to absorb heat quickly to help smooth peak summer temperatures; it will then emit it back to the space once the peak has passed, often during the night.

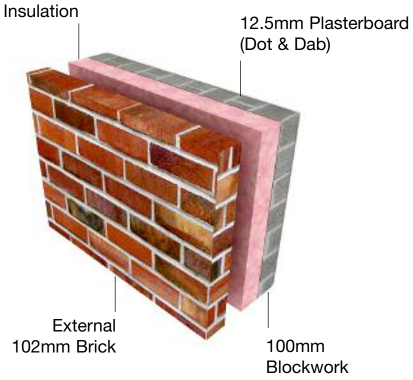
See Appendix 8 for construction details of comparative models.

Standard New Build Masonry Construction

Party wall



External wall



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The difference in thermal mass is not a significant factor

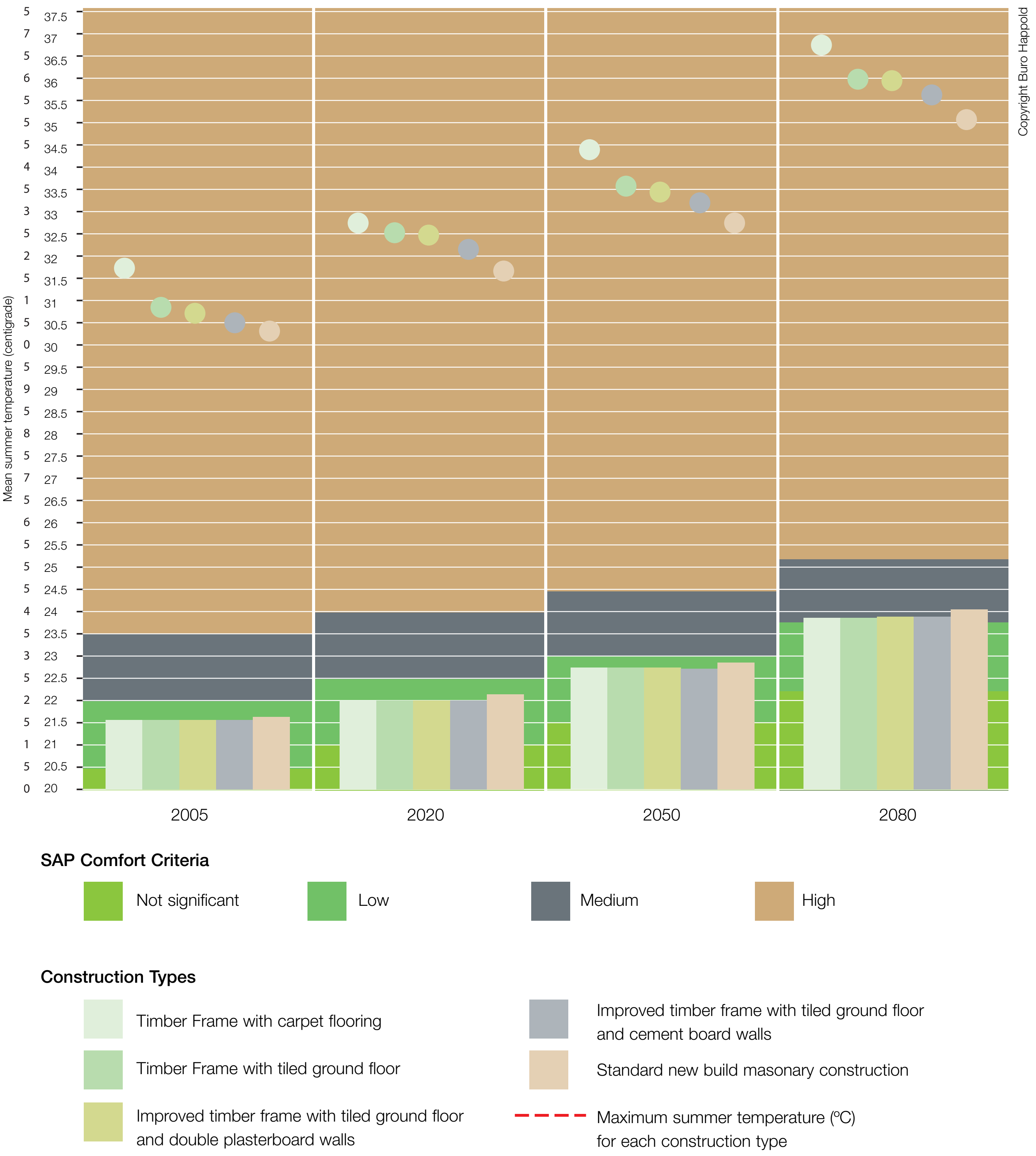
The findings of this report suggest that a number of parameters affect comfort, including external air temperature, thermal insulation, air tightness, solar gain and ventilation strategy, as well as thermal mass. And that the difference in thermal mass between standard new build masonry construction and lightweight timber frame construction, as a single comparison, is not a significant factor affecting either thermal comfort or energy consumption, either now or within the lifetime of the building.

Construction type is not a significant factor in providing summertime comfort

All types of construction, timber structure, timber structure with added thermal mass, and standard new build masonry construction, were reasonable in providing summertime comfort up to the mid point of the century without the ventilation optimization strategy. After then, all will overheat to some extent when considering the current acceptable comfort temperature. There is a marginal benefit from including high thermal mass elements, i.e. the lightweight timber frame will overheat slightly more. However, it is also true that all types of construction could be made comfortable with small adaptations. In the case of a timber structure, thermal mass could easily be added into the ground floor and surrounding walls.

All day occupancy bedroom comfort

Evening lounge comfort



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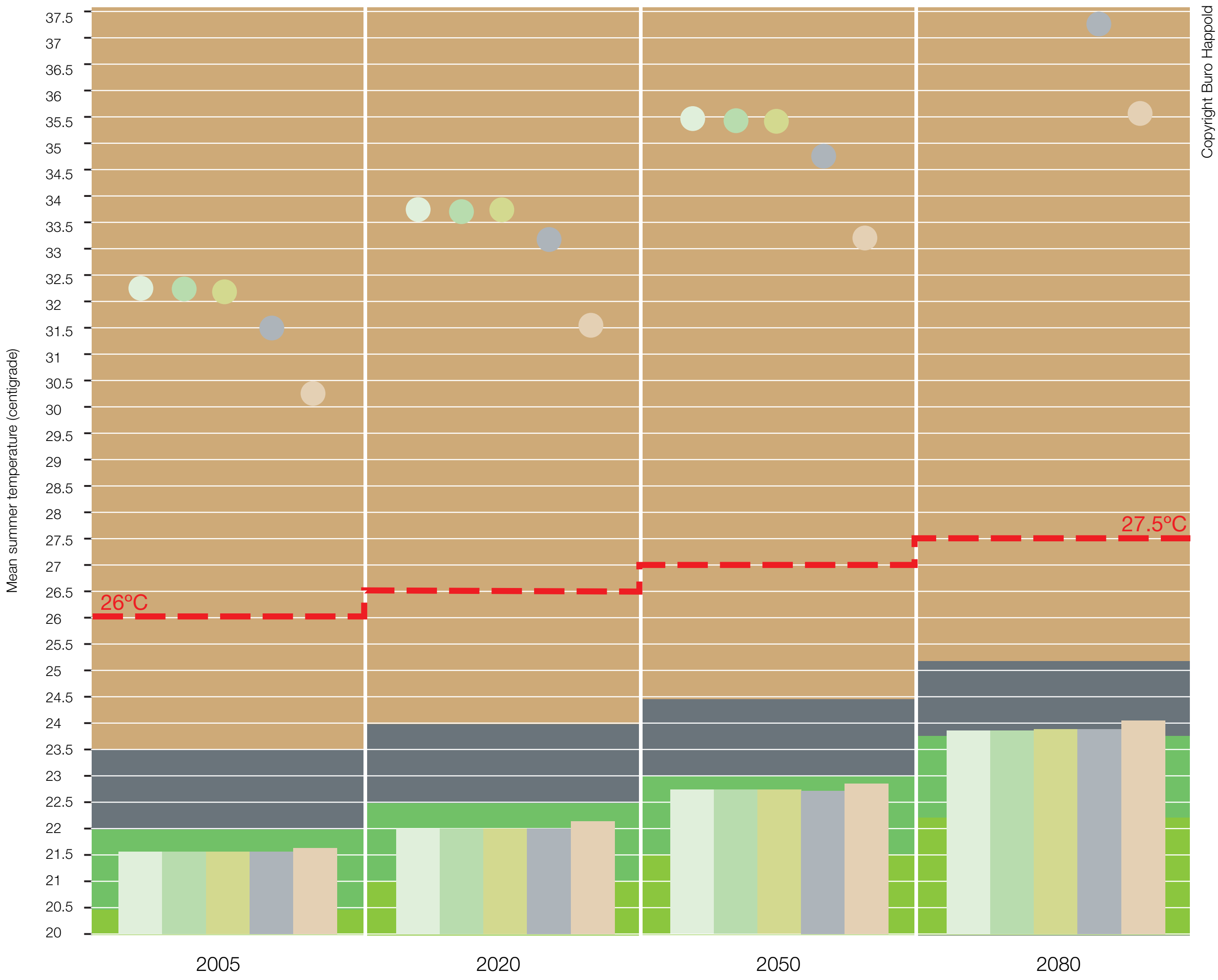
Evening bedroom comfort



SAP Comfort Criteria

- 🟩 Not significant
- 🟩 Low
- ⬛ Medium
- 🟫 High

Construction Types

- ■ Timber Frame with carpet flooring
- ■ Timber Frame with tiled ground floor
- ■ Improved timber frame with tiled ground floor and double plasterboard walls
- ■ Improved timber frame with tiled ground floor and cement board walls
- ■ Standard new build masonary construction
- – – – Maximum summer temperature (ºC) for each construction type

The importance of thermal insulation

In all the types of construction considered, even in 2080, the annual heating load still far outweighs the cooling load; so careful design with respect to heat loss remains vital for reduced energy consumption.

It is simple to build highly insulated and air-tight lightweight timber houses, and they remain an effective means of cutting energy use over the annual cycle for the foreseeable future.

The effective utilisation of thermal mass

The key when incorporating thermal mass is its utilisation. The comfort control of the most occupied areas can benefit from the careful design and application/addition of elements of higher thermal mass. The skill of the designer is crucial to achieving the maximum benefit from the thermal mass. However, there are costs involved: capital costs, in terms of embodied energy and perhaps (depending on the occupancy pattern) in the heating mode in terms of operational energy.

Thermal mass gives a benefit in maintaining comfort. However in modern day construction, the available thermal mass is generally hidden behind plasterboard. Timber structures can easily become equivalent to modern day masonry structures, through the addition of thin layers of thermal mass.

When considering future proofing our building stock, the most important point is to incorporate good design from the outset so as to manage the parameters of thermal insulation, solar gain, infiltration, thermal mass, ventilation and incidental gains.

Refurbishment of existing stock provides an opportunity to adapt buildings gradually to a changing climate. Simple measures such as the addition of solar shading, controllable ventilation or even solar powered ventilation can be added cost-effectively to existing houses.

Off-line studies showed that ventilation could have a significant benefit on exposed thermal mass, discharging the heat build-up and allowing it to absorb yet more.

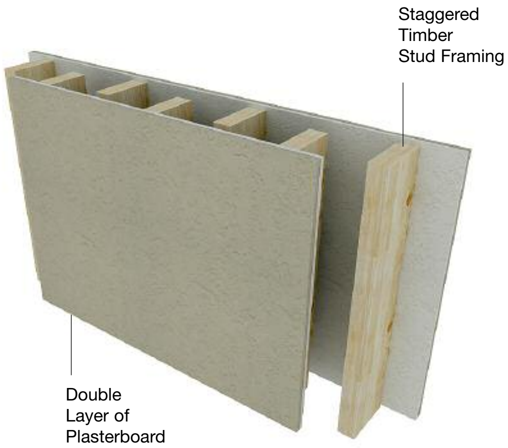
Adding thermal mass to timber structures

UK vernacular architecture will change as temperatures increase – the fashion for tiled or stone floor finishes will become more widespread, we will incorporate more solar shading, reflective exteriors, and so on. Similarly there will be a natural change in occupant behaviour, i.e. movement to rooms away from solar gain, closing curtains or shutters etc.

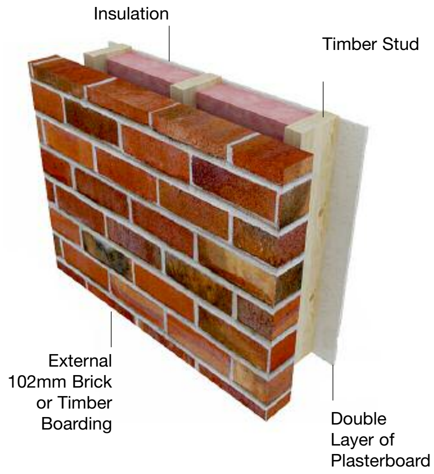
While lightweight construction methods naturally lend themselves to greater off site pre-fabrication and improved quality control in construction, they do not preclude the addition of high thermal mass elements. In the case of new-build timber framed construction, the addition of some exposed thermal mass should be considered by screeding/tiling the floors, adding a layer of plasterboard, or wet plastering solid party walls. Massive Timber Systems (such as cross laminated planks) can easily incorporate screeded ground and upper floors.

Timber frame with tiled ground floor and double plasterboard to walls

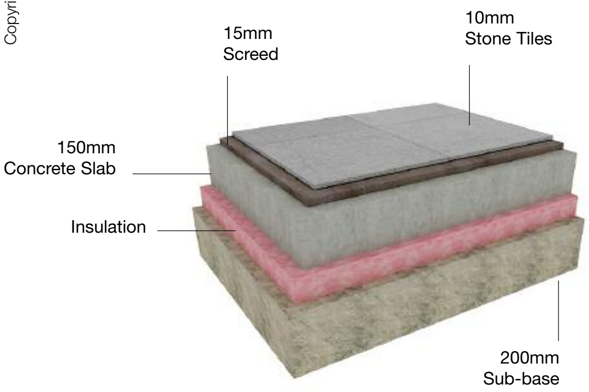
Double Layer Plasterboard Party Wall



Double Layer Plasterboard External Wall



Tiled Ground Floor



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3. Thermal efficiency:

aspects to be considered

Key Findings

Effective thermal efficiency requires a combination of passive and active strategies.

Translating low elemental U-values into good insulation requires appropriate design detail and on site workmanship to control thermal bridging and airtightness.

The implications for solar gain in hot weather as well as cold weather must be considered.

More demanding airtightness increases the importance of ventilation.

Orientation and house type play important roles in energy efficiency.

Introduction

Thermal mass is just one of the aspects of design to be considered when seeking to minimize energy usage, running costs and carbon dioxide emissions over the life of a building.

There are many solutions, both passive and active, which can be combined to

Insulation

The single most important measure for achieving thermal efficiency in new buildings and refurbishments is insulation. In the roof, in the floor, and in the walls. The maximum U-values of these elements are described in Part L of the Building Regulations and will be lowered in a series of steps towards the requirements for a zero carbon house by 2016.

Thermal bridging

However low the U-value of any individual building element, good thermal efficiency can only be achieved by minimizing thermal bridging. Good detail design, materials with inherently low thermal conductivity (like wood) and high quality site practices, or highly prefabricated structures, all contribute to controlling thermal bridging.

Air tightness

Air tightness is integral to thermal efficiency and is also specified within the Building Regulations. Effective air tightness is difficult to achieve using masonry construction because of the variability of on-site practice. Off-site fabrication, typical of closed panel timber frame systems, has a good record of achieving superior air tightness.

However, undue emphasis on air tightness, without due consideration of ventilation, can result in stuffy, unhealthy rooms.

Mechanical ventilation is increasingly seen as the best way of managing the balance, extracting the heat from stale air, and using it to warm incoming fresh air.

Solar gain

Solar gain needs to be carefully considered. Good natural lighting is critical to energy reduction and a sense of well-being, and solar gain is a significant benefit in cold weather, a factor recognized within the calculations for the BFRC's Window Energy Ratings.[1]

But as solar gain is a problem in warm weather, external shading may be needed, especially for south-facing windows. And, as glass is a poor insulator, the bigger the window area, the less well a building retains its warmth in cooler periods. So the U-value of the window as part of the whole wall needs to be taken into account, and the specification is likely to include advanced glass coatings as well as special gas filled glazing units, extra wide double glazing, and even triple glazing.

Solar gain can be combined with exposed areas of thermal mass to prolong the thermal effect. A typical example might be a south facing conservatory with a solid concrete floor and/or internal wall. Care must be taken to ensure adequate shading and ventilation to avoid overheating in the summer.

Ventilation

Effective and controllable natural ventilation is a key factor in achieving comfort during the warmer days, and often nights, of summer.

Potentially conflicting priorities need to be reconciled here too, where open ground floor windows might present a security hazard, or where upper windows might not provide adequate ventilation in child safe mode. Noise is also a consideration.

Rooms that have windows on more than one aspect will enjoy greater airflow.

Where homes have loft space, it's worth considering simple mechanical ventilation to evacuate excessive heat in the summer, without compromising heat retention in the winter.

See Approved Document F of the Building Regulations.

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[1] British Fenestration Rating Council

Orientation

Where possible, attention should be paid to the orientation of a building and its openings, both to maximize solar benefits and to minimize exposure to prevailing winds. Neighbouring buildings, topography and the opportunity to use planting for solar and wind control, should all be taken into account in the design.

House type and shape

The greater the exposed surface area, the greater the potential heat loss. Bungalows are the least thermally efficient type, flats and terraced houses the most efficient. A compact plan is beneficial, as is making maximum use of loft and cellar space.

Fairmule House courtesy of Quay 2C, London and Eurban

New technology

Because the government is now taking steps to encourage greater energy efficiency, both through the Building Regulations and through the adoption of more favourable feed-in electricity tariffs, more advanced technological solutions are becoming increasingly practical, whether passive, like dynamic thermal mass materials, or active micro-generation, like photovoltaics, solar thermal, biomass, ground or air source pumps, wind or hydro.

One, or a combination of active solutions, will be needed, along with highly effective passive measures, to meet the zero carbon house requirement of the Building Regulations and Rating Level 6 of the Code for Sustainable Homes that the government has signalled will be mandatory by 2016.

4. Climate change:

wood and low carbon construction

Key Findings

Over 90% of the wood we use comes from European forests.

European forests are growing at the rate of 661,000 hectares a year.

The forest carbon sink effect and the product carbon store effect mean wood products are ‘carbon negative’.

Using wood products from sustainably managed forests actually reduces the carbon dioxide in the atmosphere.

The ‘substitution effect’ makes the carbon dioxide emissions savings even more significant.

The more wood from sustainably managed forests you use instead of other materials, the lower the carbon dioxide emissions of your building.

Introduction

Climate change is the big issue of our time. Almost everyone now appreciates it will have a truly significant impact on the way we live, and the way our children live. It's an issue that's not going to go away; it's likely to get a great deal worse before it gets better. We are all, government, professionals, companies and individuals, looking for ways to help. We are all having to find ways to create a low carbon future.

This is nothing less than a new industrial revolution. At the end of the last century the microchip changed the way we worked and lived. We are now at the beginning of the low carbon revolution.

This is a real opportunity for wood. There is no other mainstream material that, apart from being naturally renewable, actually reduces the carbon dioxide in the atmosphere.

This is the century of building with wood.

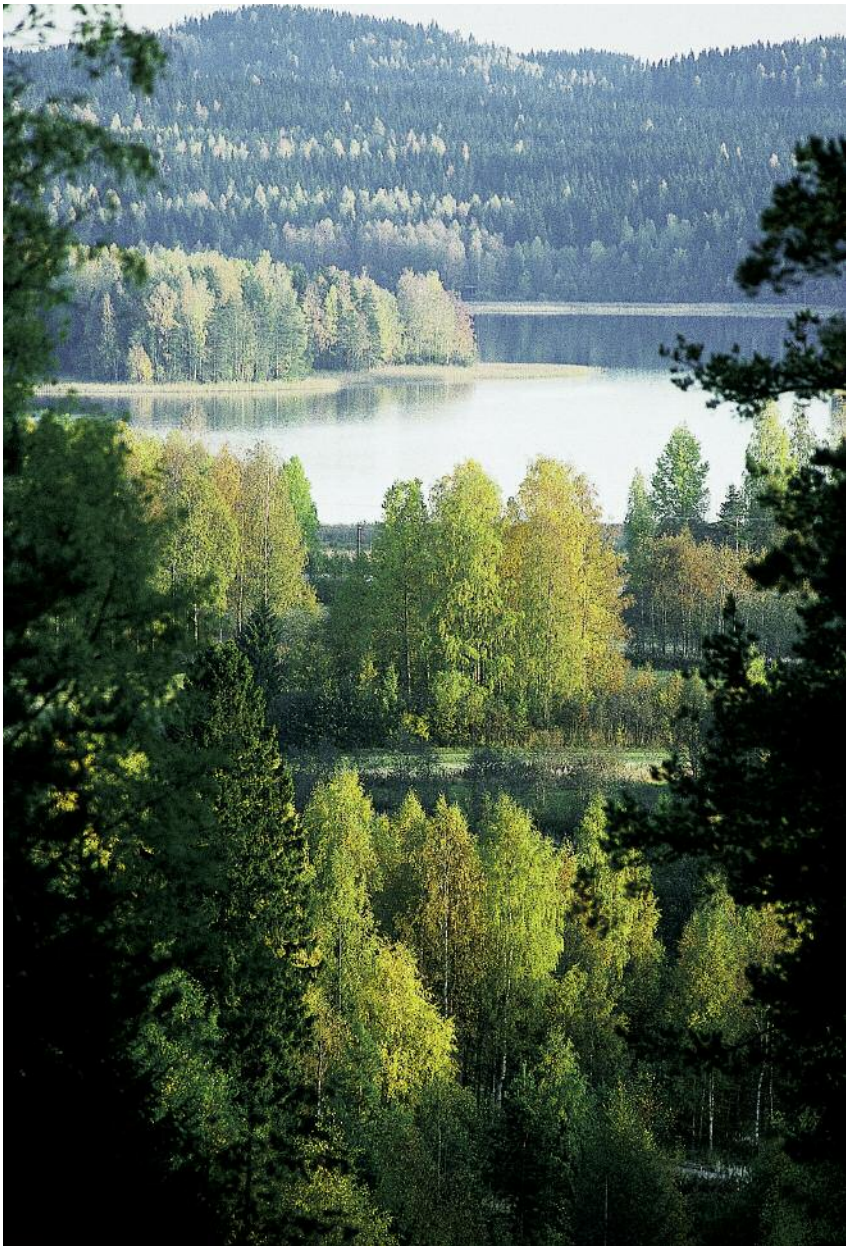
Europe's forests are well-managed and in growth.

Second only to the oceans, forests are the world's most important carbon sink. Although tropical deforestation is a major contributor to global carbon dioxide emissions, Europe's forests are well-managed and in growth.

According to the UNECE/FAO, 'Net increases in the extent of the forest, in forest plantations and in growing stock are positive trends towards sustainable forest management in the region. All indications are that European countries have successfully stabilized or increased their forest areas…'[1]

They estimate the forest is growing at a rate of 661,000 ha a year (the equivalent of three football pitches every hour of the day and night).

The great majority of the wood we use in Europe is sourced from Europe's forests - over 90%, and much of the remainder comes from well-managed forests in North America.[2]



Europe's forests are an important carbon sink

A managed forest is an efficient carbon sink, as well as providing timber and supporting livelihoods often in rural areas.

As trees reach maturity their uptake of carbon dioxide slows along with their growth. Without management, the forest reaches an equilibrium where growth and decay are in balance.

Sustainable forest management ensures mature trees are harvested, while the size of the forest is maintained or increased through a combination of afforestation and reforestation. So, far from harvest resulting in a net depletion of the forest carbon store, in fact the growth of Europe's forests is adding around half a billion tonnes of carbon dioxide annually to the current store of over 160 billion tonnes of CO_2.[3]

And the harvested wood adds to the carbon store of wood products. This combination of growing forest sink and product store is why wood products are able to have 'negative' embodied carbon dioxide.

Trees absorb carbon dioxide

A tree typically absorbs 1 tonne of carbon dioxide for every cubic metre's growth, emitting 727 kgs of oxygen.[4]

[1] UNECE/FAO, State of the World's Forests, 2007 [2] Using Wood Products to Mitigate Climate Change, 2004 [3] European Commission's DG Enterprise – Unit 4, Comprehensive Report 2002-2003 regarding the role of forest products in climate change mitigation [4] Edinburgh Centre for Carbon Management Report 196, Carbon benefits of Timber in Construction, 2006

Europe's wood products are an important carbon store

Europe's stock of wood products is estimated at 60 million tonnes of carbon, keeping 220 million tonnes of carbon dioxide out of the atmosphere.

As more wooden products, like timber frame houses, are produced, the wood product stock continues to grow.

To get the maximum CO_2 saving from wood products, it is important to extend their life through good design and maintenance, re-use and recycling, and then to recover the energy from the wood, at the end of its life, as a biomass fuel. The life of the carbon store can be extended through recycling.

The substitution effect

Even more importantly, wood products substitute for other materials, like steel, concrete, plastic or aluminium, whose production results in significant carbon dioxide emissions.

According to the Edinburgh Centre for Carbon Management, every cubic metre of wood you use instead of other building materials saves between 0.7 and 1.1 tonnes of carbon dioxide. So the more wood you use instead of other building materials, the lower the embodied carbon dioxide of your building.

Using wood saves carbon dioxide

A typical three bedroom detached house has around 20 tonnes of embodied carbon dioxide emissions. Studies have shown that just by using timber frame a saving of three tonnes can be made. However, more dramatic savings can be made by substituting timber wherever possible, including softwood cladding, windows, doors and floors. The total carbon dioxide emissions embodied in the building can be reduced by 17.6 tonnes, to just 2.4 tonnes of carbon dioxide.[1]

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[1] Edinburgh Centre for Carbon Management Report 196, Carbon benefits of Timber in Construction, 2006

Appendix 1

Advice on the measures to be taken to ensure good air-tightness and indicative detailing.

floors such as beam and block flooring, especially where the screed is not laid properly. Large area boards and tongue-and-groove edges can reduce air leakage, subject to all gaps and holes being sealed before floor coverings are laid.

Table 3: Air-tightness performance standards

10 – 5 m^3/hr.m^2 depending upon quality of workmanship	This target can be achieved by adopting 'Accredited Construction Details' (ACD) published by DCLG in June 2007. Specific details are published for different construction types including timber frame and are mandatory to achieve compliance under building regulations. Specific measures may include ***Air barriers:*** Internal lining such as plasterboard; plus 'Vapour Control Layer' (VCL) that may be integral to the internal lining (typically installed on inside face of insulation for walls, rooms in roof/ flat roofs) ***Ground Floor construction:*** - Seal gap between skirting board and floor/ wall with continuous mastic seal - For junction between timber frame wall and suspended concrete floors, DPC to be turned up behind sole plates and lapped with vertical VCL. DPC and sole plate to be sealed with mastic/ gasket. Where insulation is above the floor slab, insert VCL between floor finish and insulation layer (lapped and taped to the VCL on the walls) - For timber ground floor, glue joints in the timber floor. Tongue and groove edges for floor boards reduce air leakage compared to butt joints. For both ground and intermediate floors, apply continuous bead of sealant on timber floor deck before positioning wall panels. ***Intermediate floor construction:*** - As above, apply continuous bead of sealant on timber floor deck before positioning wall panels - Ensure continuity of air barrier through the floor void. This can be achieved through a solid nogging or header joist or alternatively by attaching a membrane to the floor perimeter beams lapped and sealed to VCL (e.g. with 1000g polythene strip stapled to the floor beams). ***Wall construction:*** - Ensure internal lining is sealed and VCL properly lapped at joints - Return VCL into door and window reveals, head and sills - Return VCL along the separating at junctions with external wall. - At junctions of internal and external walls, ensure continuity of air barrier through the partition e.g. by means of a timber stud - apply flexible sealant to front and back of window/ door frames and under sill board - cut VCL tight around electrical sockets - service penetrations to be preferably core-drilled to provide a sung fit and sealed (using appropriate sealants depending on void size and anticipated differential movement) where they penetrate the VCL/ air barrier including behind kitchen units and bath panels - ensure trickle ventilators provide sufficient level of air-tightness

	Roof construction: - Ensure internal lining is sealed at joints/ junctions - Draught stripping of loft hatches - For flat roofs, turn up VCL at edge of roof insulation; lap and seal with roof waterproofing layer Other considerations include proprietary loft hatches with low air permeability characteristics, and appropriate mounting of recessed light fittings so as to avoid penetrating the primary air barrier.
5 – 2 m^3/hr.m^2 depending upon quality of workmanship	Based on published case studies of air pressure testing for new timber frame construction, the achieved air-tightness was found to vary considerably due to variations in degree of site supervision and overall quality of workmanship. In most instances, service penetrations can significantly impact air-tightness, with values doubling from an average of 1.27 to 2.52 m^3/hr.m^2 for tested dwellings once services were installed. The following may be relevant to timber construction - Consider use of joist hangers where joists are built into the inner leaf - Consider sealing laps in internal and external membranes (use a layer of double sided tape at the overlap and then another tape over the leading edge) - When installing the internal lining/ plasterboard, consider using laying tape at junctions with ceiling and floor - Consider creating a service void between the timber frame and the plasterboard/ internal lining by having a layer of OSB sheathing nailed to the timber studs on the inside with the VCL attached to it. The plasterboard can then be nailed on to softwood battens fixed to the OSB layer. This reduces penetrations of the air barrier/ VCL to a minimum and ensures positive mechanical fixing of the VCL by battens. Downsides include loss of internal floor space and additional costs (~35% of the cost of the external wall). - Consider proprietary gasketed socket boxes - Consider creating a similar service void as walls at ceiling level with the VCL stapled to the OSB, ensuring the VCL is continuous over partition walls - Consider using a ceiling membrane e.g. polythene strip with 100m overlap each side, stapled to the top runner of frame at roof level to prevent infiltration from ventilated eaves
<2 m^3/hr.m^2	- SIP construction can achieve the required performance standards and most manufacturers claim to achieve air tightness levels of <1m^3/hr.m^2.

Please note that the above specifications have been based on published material[5] and are for general reference only. These outline the general principles to be adopted and the precise measures will depend on the specific building design and detailing. The quality of workmanship and materials (e.g. appropriate sealants depending on void size and anticipated differential movement) will greatly influence the air-tightness levels achieved.

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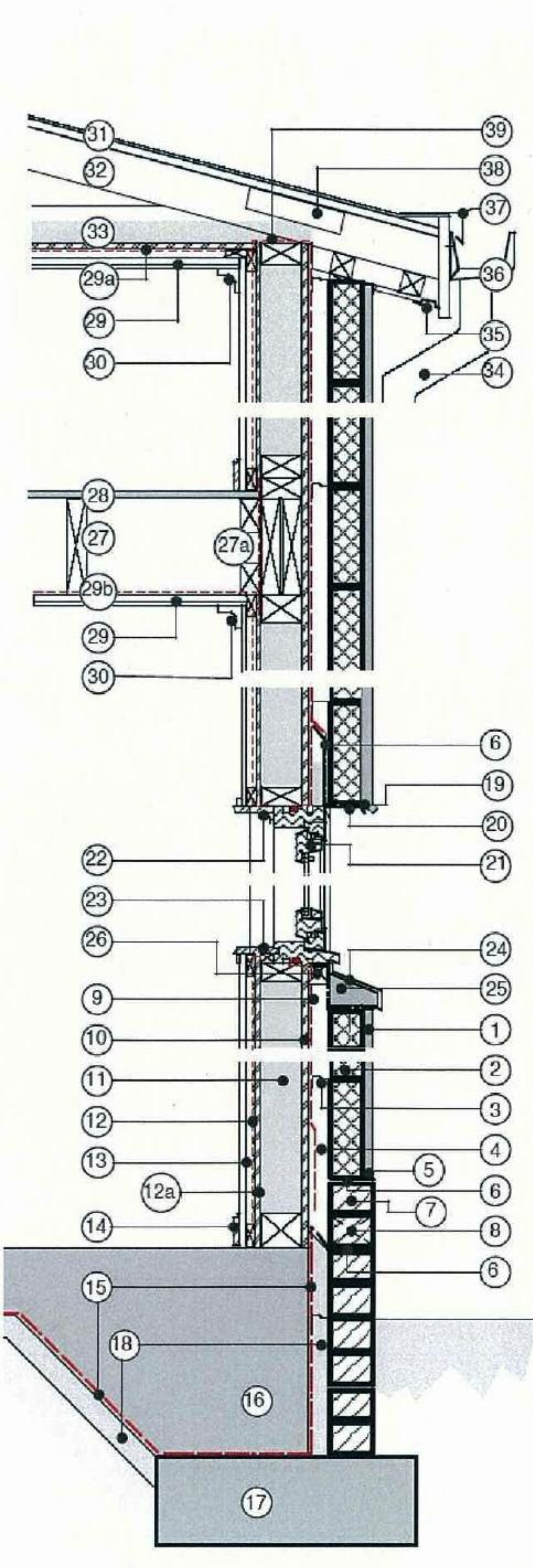
[5] *Accredited Construction Details*, Communities and Local Government, June 2007; *Design and Detailing for Airtightness – SEDA Design Guide for Scotland*, 2006; *Improving Airtightness in Dwellings*, Energy Saving Trust, November 1997; *Improving Airtightness in New Dwellings – Case Studies*, Energy Saving Trust, June 2007

Figure 1: *Indicative Detailing for Air-tightness – SEDA guidance*



1. Drydash, cement: lime: sand render to BS 5262.
2. 100mm concrete blockwork
3. Cavity wall ties mechanically fixed staggered (a)
4. 50mm ventilated cavity
5. Expamet render stop bead
6. Damp proof course, also as cavity tray over lintol
7. 100mm facing brickwork
8. Perpend weep slots @ 900mm centres
9. Breather paper fixed to ply with corrosion resistant staples (b), lapped and sealed (c), continuous at all laps and junctions (d), taken into opening reveals, sealed at corners and continuous with frame seal (e), refer 21.
10. 12.5mm sheathing ply nailed to studs
11. 95mm sw stud frame, 100mm mineral fibre quilt insulation. Frame design to BS 5268-6-1.
12. Vapour barrier (c) (d) (e) to interior face of OSB (f), lower edge taped to concrete with batten fixed over to seal.

12a. 10mm OSB board nailed to inside of studs, vapour check stapled to board (f) with 25x50 untreated sw battens horizontally to form service void (g)

13. 12.5mm plasterboard, use laying tape at junctions with ceiling, floor and openings to form airtight seals (h). Service boxes to fit within void and airtight (i)
14. 75 x 15mm MDF skirting board nail fixed to frame, continuous mastic seal to both connecting faces (j)
15. Polyethylene damp proof course dressed up edge of slab and tucked behind dpc / breather paper. (e)
16. 150mm insitu rc slab with float finish
17. Trench foundations
18. 50mm rigid eps butt jointed insulation beneath slab
19. Render stop nailed to blockwork at 600mm centres
20. Galvanized steel lintol and cavity closer to structural engineers spec. Behind lintol, run taped and sealed membrane into opening behind main membrane which laps dpc as noted over lintol, ref 6. Space behind lintol to be filled with expanding foam before installation of windows, & face sealed with mastic (k)
21. Proprietary pine tilt and turn double glazed window unit screwed to frame through continuous flexible foam on all sides to fully seal connection to frame, allow also for mastic sealant to outer face (l) Opening casements fully draughtstripped with tubular compressible seals, all to be fitted after painting and accessible for replacement (m)

22/23 15mm MDF nail fixed internal surround / cill (e), (j).

24. Aluminium ppc flashing mechanically fixed to frame
25. Precast concrete cill on 1:1:5 mortar
26. SW packer cavity closer
27. Timber joists @ 450mm centres fixed at perimeter support by mechanically fixed steel joist hangers (p) (ref. Struct. Eng.)

27a. 1000 g polythene strip stapled to inside face of perimeter floor beams, overlapping 100mm, lapped and sealed to vapour check. Ensure any damages to membrane are sealed (q)

28. 18mm tongue and groove chipboard nail fixed to joists
29. 2x 12.5mm plasterboard nailed to battens (h), ensure penetrations (eg ceiling pendants) carefully mastic sealed before concealment (n). Ensure careful sealing of loft hatch. (o)

29a 10mm OSB board nailed to underside of trusses (f), vapour check (c) (d) stapled to OSB, lapped and sealed behind battens at junction with wall. Ensure vapour control layer is continuous (lapped and sealed) over partition walls. (r) 25x50mm sw battens forming service void (g)

29b 1000 gauge polythene strip stapled to u/side of joists (u)

30. Extruded polystrene cornice glue fixed (j)
31. Proprietary single ply membrane roofing fixed to ply
32. Proprietary timber roof truss with bolted joints
33. 50mm flexible insulation (s)
34. UPVC down pipe
35. Vents within soffit
36. Aluminium ppc gutter fixed to edge board by brackets
37. Mechanically fixed angle flashing
38. Insulation stop
39. 1000 gauge polythene strip with 100mm overlap each side stapled to top runner of frame and down sides, to be taped and sealed to subsequent membranes both sides. (t)

Appendix 2

Performance details for an indicative range of timber frame/panellised systems, as well as an indication of the typical costs for each system, on a £/m^2 of floor area basis.

Please note these performance details relate to only a small number of the possible solutions provided by UKTFA members. Contact the timber frame manufacturer directly for details of the full range of solutions available.

Table 7: Matrix for energy efficiency standards for timber frame construction based on SAP calculations – Insulation thickness (timber frame walls, suspended timber floors and pitched roof)

Target HLP	**1.3**			**1.1**			**0.8**		
Dwelling type	Insulation thickness (mm)***			Insulation thickness (mm)			Insulation thickness (mm)		
	Walls	**Floor***	**Roof**	**Walls**	**Floor***	**Roof**	**Walls**	**Floor***	**Roof**
Detached house P/A ratio 0.53)	140mm rigid urethane/ PIR insulation btw studs (140 mm timber studs) + 25mm dry-lining/ insulating sheathing	130mm rigid urethane/ PIR insulation btw floor joists + 40mm vertical edge insulation	100mm mineral wool btw joists + 225 mm over joists	140mm rigid urethane/ PIR insulation btw studs (140 mm timber studs) + 90 mm dry-lining/ insulating sheathing	** 150mm rigid urethane/ PIR insulation on concrete slab/ beam and block flooring	100mm mineral wool btw joists + 300 mm over joists	140mm rigid urethane/ PIR insulation btw studs (140 mm timber studs) + 120 mm dry-lining/ insulating sheathing	** 180mm rigid urethane/ PIR insulation on concrete slab/ beam and block flooring	100mm mineral wool btw joists + 400 mm over joists
	140mm mineral wool btw studs +85mm dry-lining		150mm rigid urethane/ PIR insulation btw rafters + 70 mm below rafters			150mm rigid urethane/ PIR insulation btw rafters + 100 mm below rafters			200mm rigid urethane/ PIR insulation btw rafters + 125 mm below rafters
End-terrace P/A ratio 0.47	89mm rigid urethane/ PIR insulation btw studs (89 mm timber studs) + 20mm dry-lining/ insulating sheathing	95mm rigid urethane/ PIR insulation btw floor joists + 40mm vertical edge insulation	100mm mineral wool btw joists + 175 mm over joists	89mm rigid urethane/ PIR insulation btw studs (89 mm timber studs) + 60mm dry-lining/ insulating sheathing	150 mm rigid urethane/ PIR insulation btw floor joists + 40mm vertical edge insulation	100mm mineral wool btw joists + 300 mm over joists	140mm rigid urethane/ PIR insulation btw studs (140 mm timber studs) + 65mm dry-lining/ insulating sheathing	** 150mm rigid urethane/ PIR insulation on concrete slab/ beam and block flooring	100mm mineral wool btw joists + 300 mm over joists
	89mm mineral wool btw studs +60mm dry-lining		150mm rigid urethane/ PIR insulation btw rafters + 50 mm below rafters	140mm mineral wool btw studs +85mm dry-lining		150mm rigid urethane/ PIR insulation btw rafters + 100 mm below rafters	140mm mineral wool btw studs +140mm dry-lining		150mm rigid urethane/ PIR insulation btw rafters + 100 mm below rafters
Mid terrace P/A ratio 0.25	89mm rigid urethane/ PIR insulation btw studs (89 mm timber studs) + 15mm dry-lining/ insulating sheathing	75mm rigid urethane/ PIR insulation btw floor joists + 40mm vertical edge insulation	100mm btw joists + 175 mm over joists	89mm rigid urethane/ PIR insulation btw studs (89 mm timber studs) + 20mm dry-lining/ insulating sheathing	90mm rigid urethane/ PIR insulation btw floor joists + 40mm vertical edge insulation	100mm mineral wool btw joists + 175 mm over joists	140mm rigid urethane/ PIR insulation btw studs (140 mm timber studs) + 15mm dry-lining/ insulating sheathing	130 mm rigid urethane/ PIR insulation btw floor joists + 40mm vertical edge insulation	100mm mineral wool btw joists + 300 mm over joists

Appendix 3

An assessment of renewable energy technologies, strategies and costs to reach different Code levels.

4.3.2 Available LZC technologies

An overview of available 'low and zero carbon' (LZC) technologies is given below:

Solar Hot Water (SHW) - Solar water heating in the UK is designed to provide pre-heating for domestic hot water use. The best way to accomplish this in houses or flats is to have roof mounted panels with a closed water loop feeding a twin-coil hot water storage cylinder. When the sun is shining, water is pumped through the solar panel and is heated by solar energy. This heated water then flows through a heat exchanger, warming the water stored in the hot water cylinder. If necessary, a boiler provides top-up heating.

They are normally sized to provide 50-60% of annual hot water demand. This is a simple and low cost technology with minimal maintenance requirements. In terms of system efficiency, consideration needs to be given to orientation, tilt and minimising shading from adjoining properties. SHW systems are most effective on roofs facing ± 25° due south and installed at an inclination of 30°. In the UK, a north-facing SHW roof will operate at about 60% efficiency. There are two main types of solar thermal collectors available - flat plate and evacuated tube. While the flat plate collectors are simpler and cheaper per square metre, the evacuated tubes have a relatively higher efficiency. Evacuated tube collectors, can have their fins rotated in the factory to the optimum solar angle and can therefore be fitted vertically or horizontally without losing any efficiency. This allows further opportunities for architectural integration.

Medium/ large wind turbine - This is the most economic form of renewable energy in the UK for semi-urban and rural areas where high wind speeds are prevailing. A wind turbine consists of rotor blades and hub mounted on a mast. The blades pick up the wind and drive the built-in generator which produces direct current (DC) electricity. In order to use this power it is conducted to an inverter and transformed into AC electricity. The theoretical wind to power conversion efficiency is up to 60% but in practice it is lower than that. A more relevant factor is the capacity factor, which rarely exceeds 30% of the year and is more likely to be 8-15% in urban areas as the output is reduced by the lower wind speeds and turbulence. Knowledge of the local wind is critical to siting a wind turbine and predicting its output. As wind power is proportional to the cube of the wind's speed, relatively minor increases in speed result in large changes in potential output.

The ideal characteristics of a site are relatively strong and constant winds and clear exposure, free from excessive turbulence and obstructions such as large trees, houses or other buildings. Issues such as visual impact and noise must be considered. The distance to the nearest dwelling is determined by the design of the wind turbine, the ambient noise levels in the area, and the potential for shadow flicker. In general, it is recommended that the turbine noise level is kept to within 5 dB(A) of the average existing evening or night-time background noise level. Typically this means that a large to medium scale wind turbine has to be located at a distance of at least 350m – 400m from any dwellings in order to maintain noise at the required levels (35-45 dB). The impact of shadow flicker can increase this distance further, particularly if the turbine is sited to the south of any dwellings.

Small scale wind turbines - Small-scale installations can be either ground mounted or roof-mounted depending on actual size of the machine, available space and height, and the structural integrity of the building. Building-integrated wind turbines are still considered innovative, despite the already widespread use of larger scale wind turbines in wind farms. The integration of wind turbines in building projects requires a very early commitment to deal with architectural and structural integration. There is also a significant amount of risk when dealing with wind speed estimates in a turbulent environment.

It is however a technology that is evolving and some products have been developed explicitly to cope with the technical and planning constraints of building-integrated wind turbines, resulting in a great variety of wind turbine types. Vertical axis turbines are more resilient to local turbulence and changes in the wind direction; others are specially designed to work under low wind speeds, therefore producing electricity even in fairly low wind conditions. However, the performance of the turbine will vary greatly with local conditions depending on the height, form and layout of surrounding buildings or features.

Photovoltaics - Photovoltaic cells (PV) produce electricity directly from sunlight. The technology consists of PV cells connected together in PV modules (panels or arrays) which are semiconductors, typically made of crystalline or amorphous silicon. When exposed to sunlight, the PV cells produce direct current (DC) electricity, which in order to use in the home is conducted to an inverter and transformed into AC electricity. The PV cells respond to both direct and diffuse solar radiation, meaning that even in overcast days a PV system can produce electricity. The output however is greater when there is more sunshine. The conversion efficiency ranges between 5-15%.

PV is an established straightforward renewable technology in the UK, appropriate for most homes with sufficient roof space and facing within 25 degrees of due south. Roof spaces should not be shaded by objects like tall trees or neighbouring buildings as even minor shading can result in significant loss of energy. Façade mounted panels produce around 20% less energy than an equivalent area of roof mounted panels. Photovoltaic systems can also be incorporated into the actual building fabric, for example PV roof tiles are now available which can be fitted as would standard tiles.

PV technology can demonstrate a visual statement of the development’s positive attitude towards sustainable energy solutions. However, the capital costs associated with PV technology are high compared to the contribution they make in reducing CO_2 emissions. To save costs on components such as inverters it may be more cost effective to have larger installations, such as in apartment blocks.

Ground/ water/ air source heat pumps – Heat pumps are electrically powered systems that extract low-grade heat from the air, ground, river or lake and convert it into high-grade energy, which can be used to provide both space heating and hot water in buildings. These are typically sized to meet 100% of the heating and hot water demand of the household. A heat pump operates like a refrigerator in reverse. A water/anti-freeze mixture is pumped through a pipe in the ground/ water where it absorbs heat. A heat exchanger then extracts the absorbed heat and transfers it to the heat pump, where, using electricity, the temperature is raised several times.

Ground source heat pumps are now considered to be an established low carbon technology and are typically installed with lengths of pipe buried underground in either a horizontal trench (1.5 - 2 m deep) with a straight or coiled pipe ('slinky') or vertical boreholes. Slinkies increase the amount of heat absorbed from the ground and so enhance performance. Where space is limited, vertical boreholes are used and can be 15-150m deep. A prerequisite to the installation of GSHPs is a geological survey. Water source heat pumps consist of a closed water loop in the riverbed or an open loop system where water from the river or lake is abstracted and recharged back. Water source heat pumps are less efficient compared to GSHPs due to the temperature of the source being more affected by the weather, but have much lower istallation costs. Air source heat pumps are the least efficient, but have much lower capital costs.

Heat pumps work best in new houses which are designed with their installation in mind, including a low temperature heating system using under-floor heating or oversized radiators, a building with high thermal mass and large hot water storage facilities. Heating and hot water control systems need to be set up to maximize the use of cheap night time electricity, and users need to be made aware of this. Such an integrated design can lead to a very high level of thermal comfort. However, heat pumps have higher life cycle costs per tonne of carbon abated compared to other technologies. This is due to the currently high price ratio between electricity (needed to operate the heat pump) and gas (as the alternative heating fuel).

Biomass heating - Burning wood is considered approximately neutral in terms of carbon dioxide emissions, as trees and vegetation absorb CO_2 during their life which is released on burning the fuel. Solid biomass fuels are seeing a resurgence as a result of planning requirements for renewable energy, and the technology is becoming more mature. Biomass boilers are an established technology with fully automated models available. Until recently wood fuelled heating has had the drawback of a lack of controllability. Automatic wood fuelled boilers and many stoves overcome this problem by utilising thermostats, which automatically control fuel and air intake with very responsive and programmable temperature settings.

There are three main fuel options available - logs, pellets and chips. There is a large range in price depending on volume, length of contract, specification of fuel, and method of delivery. Waste arisings attracting 'gate fee' from landfill avoidance are the cheapest fuel available, followed by forest residues, timber industry offcuts, arisings, and agricultural residues.

Logs are the most easily available and common form of wood fuel in the UK. They are often used in wood burning stoves for direct room heating but can also heat water for central heating systems - either in a stove with a back boiler or a log burning boiler designed for burning this fuel. As with logs, wood pellets and chips can be used as fuel for stoves (with or without back boilers) and pellet burning boilers are especially designed for the purpose. Pellet stoves and boilers can operate at high efficiencies of around 90%. Integral fuel hoppers store enough pellets for 1 to 3 days operation and the ash pan only needs emptying between once a month and once a year. Wood pellet boilers are fully automatic and almost as convenient as using gas or oil once the fuel is loaded in a hopper. They are well suited to meet variable load demands and can be operated on a timer.

For larger developments with communal systems, an allowance for a variety of delivery vehicle types ensures full flexibility when negotiating with potential biomass suppliers. This should include allowance for up to a 15m long five axle articulated lorry which would off-load by reversing into a ground level store with double height access doors; tipping into a basement store; or blowing the fuel into the store using a pipe. For communal plants, the height of the flue would be between 3 and 9 meters above the roof line or highest openable window depending on the proximity and height of adjacent blocks and the proposed roof use. The height of the flue for exhaust gases may be a potential planning issue but an appropriate design response, such as locating the flue near stairwells, will help minimise its visual impact.

4.3.3 Implications of small scale turbines and BIPV

Roof mounted wind must demonstrate compliance with Part A of the Building Regulations relating to structure. This is to ensure that the fixing system and the building structure are adequate to take the load and forces generated by the turbine. Certain installers may be able to self-certify that the work meets the requirements of all aspects of the regulations. A report by Energy Research Unit, CCLRC[9], investigating the feasibility of building mounted/ integrated wind turbines established the need to identify the load characteristics of a given type of wall (masonry, concrete or timber), chimney or roof structure in order to assess the maximum rated capacity that can be attached and possible combinations of attachment methods. In the absence of any guideline structural criteria, a case by case approach would need to be adopted. However, timber frame and trusses can be pre-engineered to take the turbine loads, such as in the case of the recently marketed *ruralZED* house.

Typically wind turbines are mounted on a steel or aluminum mast that is attached to the building structure through noise and vibration isolation mountings. All roof-mounted systems will transmit some energy to their support structure. Good designs will seek to minimise the intensity of the vibration source and limit its transmission to the structure. Experience of the effectiveness of different systems is still accumulating in this area. It is also likely that the mountings themselves will not be able to eliminate all source vibration and will rely on the structure to damp out their vibrations to bring them to acceptable levels. The extent to which a building can do this depends greatly on the building structure and geometry. Inherently heavy weight structures are likely to outperform, however, a number of other factors may affect this. BS7385 describes a method for assessing the vibration levels likely to cause damage to a building. This takes into account amongst other things the nature of the vibration (transient, impulse or continuous), its strength, the nature of the structure (such as light-framed domestic or heavyweight industrial), and the natural frequency of the building. The latter is related to the shape, size and structure of the building.

With regard to building integrated/ mounted PVs, there are a number of different products and fixing techniques. The critical issues are adequately ballasting the mounting frame or fixing to a suitable structural member (taking into account static and wind loads), and ensuring that all roof

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[9] The Feasibility of Building-Mounted/ Integrated Wind Turbines (BUWTs): Achieving their potential for carbon emission reductions, Energy Research Unit, CCLRC (Council for the Central Laboratory of the Research Councils), May 2005 (available at http://www.eru.rl.ac.uk/pdfs/BUWT_final_v004_full.pdf)

penetrations are properly sealed. The position, number and weight of the PV modules should be taken into account during the design of timber trusses or any other alternative roof structure.

4.3.4 Code compliance matrix

A number of scenarios were explored to achieve compliance with the range of carbon reduction targets for all four dwelling types. These are tabulated in Table 5 and Table 11. A summary of the indicative costs associated with the energy measures identified is shown in Table 12 below. The first point to note is that the sizing of the renewable energy technologies at each Code level is the same whether the dwellings are of timber frame or masonry construction, and therefore the costs for each are the same. Secondly, the figures reflect that as the sizing of any renewable energy technology reduces as a dwelling's HLP increases, the cost per unit also reduces. Comparing the costings in Table 12 with those for energy efficiency solutions in Table 9, however, it will be seen that the reduction in capital cost for the renewable energy technologies is generally not sufficient to offset the comparable increase in fabric cost seen as the HLP increases.

Code Level 3: A 25% reduction in carbon emissions from Part L regulated energy uses can be achieved through a combination of energy efficiency measures and renewable energy technologies or alternatively purely through enhanced energy efficiency standards for detached and semi-detached houses with relatively larger exposed areas. At lower levels of energy efficiency, solar water heating is an established low risk technology to achieve the Code 3 target. For high rise flats, the application of this technology may be limited by the available roof area, and a communal system may be preferable to avoid the space implications of individual pipe runs to flats on each level.

In general, the application of wind technology is constrained by site-specific conditions such as wind speed and turbulence.

Air or ground source heat pumps, may again be an appropriate solution for Code level 3 for areas not connected to the gas grid. This is because these operate on electricity and therefore their financial performance largely depends on the alternative heating fuel and the price difference between that and electricity. In urban areas where gas is commonly available, ASHPs may have higher running costs than a gas boiler if the price ratio of electricity to gas is greater than 1:2 (or greater than 1:3 in the case of GSHPs). Heat pumps work best in dwellings designed with their installation in mind, including a low temperature heating system using under-floor heating or oversized radiators, a building with high thermal mass and large hot water storage facilities.

In terms of carbon savings, the 25% reduction is achieved compared to a revised TER figure (higher than the TER for a gas heated dwelling) and is calculated by multiplying the carbon emissions for space heating and hot water by the fuel factor which is 1.0 for gas, 1.17 for oil and 1.47 for electrically heated dwellings. The higher fuel factor raises the TER and therefore makes it more attainable for heating fuels that inherently have high carbon emissions per kWh of energy generated. However, heat pumps, although electrically driven, are also highly efficient, achieving Coefficients of Performance (CoP) between 1.75 and 4.0. Such systems can therefore achieve the 25% reduction over TER with minimal fabric energy efficiency measures.

Where renewable technologies are used to achieve code compliance to Level 3, the net additional cost for delivering the amount of renewable energy required over and above the base cost of each dwelling is approximately as follows: Note: the percentages quoted here relate to the timber frame dwellings only:

> Detached: 1.3% to 4.5% (modelled based upon a building with a HLP of 1.3. For dwellings with HLP of 1.1 and 0.8, Code level 3 is achieved with energy efficiency measures only)
>
> End Terrace: 1.8% (min with building HLP of 1.1) to 6.8% (max with building HLP of 1.3).

With HLP of 0.8 Code Level 3 is achieved with energy efficiency measures only.

Mid Terrace: 1.9% (min with building HLP of 0.8) to 7.7% (max with building HLP of 1.3)

Flat: 0.7% (min with building HLP of 0.8) to 6.2% (max with building HLP of 1.3)

Clearly, the results generate quite wide ranges when viewed in percentage terms. This is reflective of two issues. Firstly, there is presently quite a variance in the comparative cost of the technologies considered in this study. In each case, the wind technology is generally the lowest cost option, although clearly the use of this is determined by site constraints. Where an element of biomass secondary heating would be required in conjunction with either solar water or PV, this is generally the most expensive option on a cost per dwelling basis.
Secondly, as noted earlier, it will be appreciated that given that the sizing of any renewable energy technology reduces as a dwellings' HLP increases, the cost per unit also reduces.

Code Level 4: The most appropriate technology to achieve Code level 4 compliance ranges from solar water heating combined with biomass secondary heating[10] in the living room (such as a log fire) for highly efficient large detached dwellings to biomass communal heating (sized to provide a percentage of the total heating load) for a block of flats. Again, GSHPs/ ASHPs may be an option for areas not connected to the gas grid, and subject to suitable ground conditions where vertical boreholes are considered. In semi urban/ rural areas wind turbines may prove cost effective depending on local terrain, wind speed and height of surrounding features (such as trees or buildings). For larger schemes considering a combination of solar hot water and PVs, consideration will need to given to building orientation and over shading at the master planning stage.

At Code Level 4 compliance, the net additional cost for delivering the amount of renewable energy required over and above the base cost of each dwelling is approximately as follows:

Detached: 2.2% (min with building HLP of 0.8) to 8.2% (max with building HLP of 1.3)

End Terrace: 3.0% (min with building HLP of 0.8) to 11.0% (max with building HLP of 1.3)

Mid Terrace: 4.9% (min with building HLP of 0.8) to 12.7% (max with building HLP of 1.3)

Flat: 2.90% (min with building HLP of 0.8) to 10.0% (max with building HLP of 1.3)

As with Level 3 compliance, the wind technology is generally the lowest cost option, with the higher cost being seen where an element of biomass secondary heating would be required in conjunction with either solar water or PV. Biomass heating as a stand alone option is introduced at this level of Code compliance.

In comparison to the situation under Level 3, there appears to be less significant variance in the sizing of plant as the HLP increases, and, therefore, less variance in cost for the renewable technology options as the HLP changes, albeit that the trend is still a general reduction in cost as the energy efficiency levels increase, as Level 3.

Code Level 5: To achieve a 100% reduction in carbon emissions from Part L energy uses, a combination of biomass heating and PVs is the most cost effective option in areas not suited to wind technology. Depending on the size and mix of uses for new developments, the area of PVs required can be substantially reduced where gas/ biomass CHP becomes viable, such as those with a significant summer hot water load. When going for biomass based heating system and Code level 5, it makes little financial case to aim for HLP of 0.8. This is because the PVs are

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[10] Within SAP, the secondary heating system for the dwelling provides 10% of the total space heating demand. Where no secondary heating system is specified the default specification is 10% of space heating load from electric room heaters.

sized to provide the electricity required for fans, pumps and lighting, as well as to offset the marginal emissions from the use of the biomass fuel[11]. With a HLP of 0.8, the electricity required to run the mechanical ventilation systems increases thereby resulting in no net reduction in the overall area of PVs required.

There is a considerable increase in plant sizing and cost at Code Level 5 compliance. The net additional cost for delivering the amount of renewable energy required over and above the base cost of each dwelling is approximately as follows:

Detached: 11.0% (min with building HLP of 0.8) to 21.8% (max with building HLP of 1.3)

End Terrace: 12.0% (min with building HLP of 0.8) to 25.2% (max with building HLP of 1.3)

Mid Terrace: 13.0% (min with building HLP of 0.8) to 26.1% (max with building HLP of 1.3)

Flat: 10.1% (min with building HLP of 0.8) to 20.1% (max with building HLP of 1.3)

As noted above, a combination of biomass heating and PV is the most cost effective option in areas not suited to wind technology.

Code Level 6: As with Code level 5, a combination of communal biomass boilers/ CHP and PVs may be the most cost effective solution for large developments with high densities, particularly blocks of flats and terrace housing.

For individual houses the carbon reduction can be achieved though a combination of solar hot water, wood-burning stove for residual heating (space heating and hot water) demand, and roof-mounted PVs. The solar thermal panels are expected to provide around 50 -60% of the annual hot water and a 2- 5kW wood-burning stove would provide the residual heating load for the houses. The wood burning stove is assumed to have no additional capital cost compared to a gas boiler and considering the high levels of energy efficiency will require a small storage space (approximately 0.25-0.5 m^3 for a weekly delivery[12]) for the biomass fuel. The remainder of the carbon reduction target can be provided by grid-connected photovoltaic panels located on the roof. Depending upon the building form, modifications may be required to the roof design to maximise south facing roof area.

The net additional cost for delivering the amount of renewable energy required over and above the base cost of each dwelling is approximately as follows:

Detached: 18.3% to 26.4%

End Terrace: 21.0% to 36.2%

Mid Terrace: 22.9% to 39.5%

Flat: 16.9% to 30.2%

As with Level 5, a combination of biomass heating and PV is again the most cost effective option in areas not suited to wind technology.

A HLP of 0.8 is mandatory at Code Level 6. Therefore, the costs are based upon dwellings achieving this level of HLP only.

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[11] Although biomass is generally refereed to as carbon neutral fuel, a carbon factor of 0.025 $kgCO_2/kWh$ is assumed in SAP to take into account the emission associated with the transport of fuel.

[12] It may not always be possible or practical to have weekly deliveries and therefore larger fuel stores may need to be considered for less frequent delivery periods.

4.3.5 *Whole Life costs*

The detailed costings in this report comprise initial capital cost only. As previously noted, for a well designed and construction dwelling, the whole life cost implications for the structural and thermal insulation solutions within either a timber frame or masonry construction should not be significantly different.

The major services option incorporated into a development to meet the required carbon or water use reduction targets, however, could have a significant impact over, say, a 30 year period. Each of the available renewable technologies will have different implications in terms of the cost of operation, maintenance and plant replacement over their intended life. By way of comparison, Figure 2 and Figure 3 provide an indication of the relative on-going costs of each system over a notional 30-year period, on a £ per £1,000 of installed capacity basis. The first graph gives an indication of the comparative whole life cost per £1,000 of installed capacity. The second graph provides a representation of the cost profile for each of the technologies over a typical 30-year period. These graphs have been compiled from data drawn from a range of projects within which Cyril Sweett have been involved.

The graphs present figures for

Photo voltaic
Wind turbines
A district system (based upon biomass)
Heat pumps, and
Solar thermal

The analysis includes the routine annual maintenance requirements of each of the systems and omissions for the corresponding system or technology that they would replace. This data raises a number of interesting points.

Whilst all of the renewable technologies should generate savings in fuel costs in the long term they will not generally produce an overall payback over their life cycle.

The payment profile of each technology is generally low, for the PV, wind, heat pump and solar thermal systems as would be expected from relatively passive systems. The main costs generally relate to the replacement of inverters, and, if applicable, the complete replacement at the end of the period, as can be clearly seen in the wind turbine example.

In respect of biomass, the graphs illustrate the data based upon a district system. The figures identify that savings should be generated through the inclusion of the biomass district heating system. This is primarily because with a district heating system a benefit accrues from the economies derived from the omission of the individual domestic boilers and replacement with a communal system.

Figure 2: Whole life costs of renewable technologies

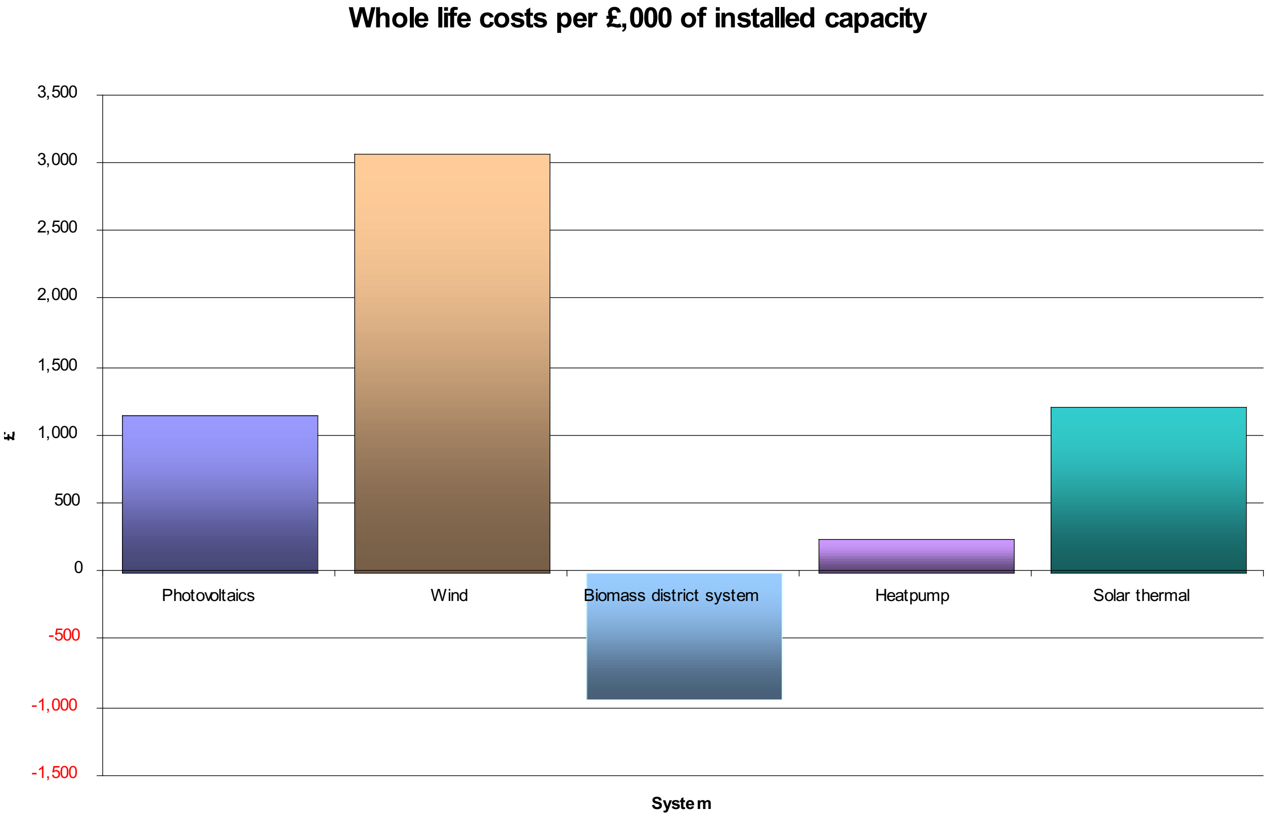


Figure 3: Cost profile for renewable technologies over a typical 30-year period

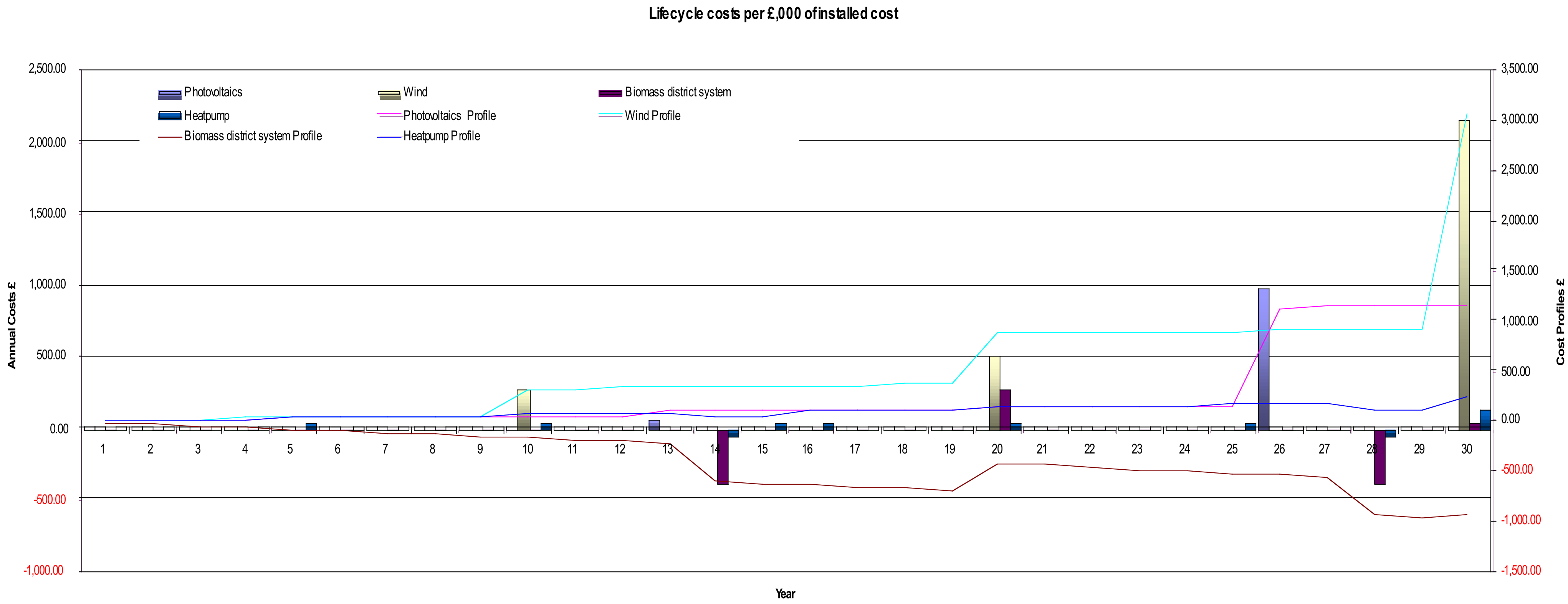


Table 11: Code compliance matrix – Energy

Code Level		**3**					**4**					**5**					**6**				
Carbon reduction target		25%					44%					100%					100% + energy for appliance use				
		Renewables					Renewables					Renewables					Renewables				
	HLP	Solar* (m^2)	PV** (kWp)	Heat pumps	Wind*** (kW)	Biomass	Solar* (m^2)	PV (kWp)	Heat pumps	Wind (kW)	biomass	Solar* (m^2)	PV (kWp)	Heat pumps	Wind (kW)	biomass	Solar* (m^2)	PV (kWp)	Heat pumps	Wind (kW)	biomass
Detached	1.3	3.0	0.50	ASHP	0.6	-	4m^2 + 1.0 kWp		GSHP	2	indiv. boiler	4m^2 + 4.0 kWp		-	6	indiv. boiler + 2.0 kWp PV					
	1.1						4m^2 + 0.5 kWp		GSHP/ ASHP	1.5	indiv. boiler	4m^2 + 3.75 kWp		-	5.5	indiv. boiler + 1.8 kWp PV					
	0.8						4.0 + Bio SH	0.5 + Bio SH	GSHP/ ASHP	1	indiv. boiler	4m^2 + 3.20 kWp		-	5	indiv. boiler + 1.8 kWp PV	4m^2 + 6.1 kWp		-	8.5	SWH+ wood-burning stove + 4.7kWp PV SWH+ wood-burning stove + 6.0 kW wind turbine
End terrace	1.3	4.0 + Bio SH	0.50 + Bio SH	ASHP	1	-	4m^2 + 1.0 kWp		-	2	comm. / indiv. boiler	4m^2 + 3.3 kWp		-	5	comm./ indiv. boiler + 1.5 kWp PV					
	1.1	2.0	0.40	ASHP	0.6	-	4m^2 + 0.6 kWp		GSHP	1.5	comm. / indiv. boiler	4m^2 + 2.9 kWp		-	4.5	comm./ indiv. boiler + 1.4 kWp PV					
	0.8						4m^2 + 0.25 kWp		ASHP/ GSHP	1	comm. / indiv. boiler	4m^2 + 2.6 kWp		-	4	comm./ indiv. boiler + 1.4 kWp PV	4m^2 + 5.1 kWp		-	7	comm./indiv. boiler+ 3.9 kWp PV comm./indiv. boiler+ 5.0 kW wind turbine
Mid-terrace	1.3	4m^2 + 0.35		ASHP	1	-	4m^2 + 1.1		-	2	comm.	4m^2 + 3.1		-	4.5	comm./ indiv.					

Code Level		3					4					5					6				
Carbon reduction target		25%					44%					100%					100% + energy for appliance use				
		Renewables					Renewables					Renewables					Renewables				
	HLP	Solar* (m^2)	PV** (kWp)	Heat pumps	Wind*** (kW)	Biomass	Solar* (m^2)	PV (kWp)	Heat pumps	Wind (kW)	biomass	Solar* (m^2)	PV (kWp)	Heat pumps	Wind (kW)	biomass	Solar* (m^2)	PV (kWp)	Heat pumps	Wind (kW)	biomass
		kWp					kWp				/ indiv. boiler	kWp				boiler + 1.5 kWp PV	▨	▨	▨	▨	▨
	1.1	4m² + 0.35 kWp		ASHP	1	-	4m² + 1.0 kWp		GSHP	2	comm. / indiv. boiler	4m² + 3.0 kWp		-	4.5	comm./ indiv. boiler + 1.4 kWp PV	▨	▨	▨	▨	▨
	0.8	2.0	0.15 + Bio SH	ASHP	0.6	-	4m² + 0.5 kWp		GSHP	1.5	comm. / indiv. boiler	4m² + 2.5 kWp		-	4.0	comm./ indiv. boiler + 1.4 kWp PV	4m² + 5.1 kWp		-	7	comm./indiv. boiler+ 3.9 kWp PV comm./indiv. boiler+ 5.0 kW wind turbine
Flats	1.3	4m² + 0.25 kWp		ASHP	1	-	4m² + 0.9 kWp		-	2	comm. boiler	4m² + 2.7 kWp		-	4	comm. boiler + 1.1 kWp PV	▨	▨	▨	▨	▨
	1.1	4.0	0.35	ASHP	0.6	-	4m² + 0.65 kWp		GSHP	1.5	comm. boiler	4m² + 2.45 kWp		-	3.5	comm. boiler + 1.1 kWp PV	▨	▨	▨	▨	▨
	0.8	1.0	0.15	ASHP	0.25	-	4m² + 0.35 kWp		GSHP	1	comm. boiler	4m² + 2.20 kWp		-	3.5	comm. boiler + 1.2 kWp PV	4m² + 4.3 kWp		-	6	comm. boiler + 4.0 kWp PV comm. boiler+ 4.0 kW wind turbine

▨ Not applicable due to mandatory energy efficiency requirements for CSH 6

▒ Not applicable as target achieved purely with energy efficiency measures

🟨 Options for renewable technologies

☐ Renewable technologies not suited for the target

Notes:
Bio SH refers to biomass secondary heating (e.g. open fire in the living room) providing 10% of the space heating demand

* Net area for flat-plate solar collectors installed at an inclination of 45° and facing ±30° south, a combined solar store with a capacity of 80 litres, and an electrically driven solar pump.

** Based on a power factor of 0.135kWp/m^2, roof mounted at an inclination of 45° facing ±30° south

*** Energy generated is dependant on site specific conditions including local wind speed, terrain and wind patterns created by adjoining structures. Calculations assume a wind speed of 5.5 m/s and a conservative load factor of 7%

Communal biomass systems not considered for large houses, although they may be feasible depending upon the density and scale of development, especially so for larger mixed-use developments.

Table 12:Summary of costs for renewable technologies for each dwelling type

Code Level		3	4	5	6
	HLP				
Detached	1.3	£ 1,320 - £ 4,500	£ 4,400 - £ 5,400	£ 13,200 - £ 21,600	▨
	1.1		£ 3,300 - £ 5,850	£ 12,100 - £ 20,475	▨
	0.8		£ 2,200 - £ 5,400	£ 11,000 - £ 18,000	£ 18,120 - £ 31,050
End terrace	1.3	£ 2,200 - £ 5,000	£ 4,400 - £ 8,100	£ 11,000 - £ 18,450	▨
	1.1	£ 1,320 - £ 4,500	£ 4,400 - £ 6,300	£ 9,900 - £ 16,650	▨
	0.8		£ 2,200 - £ 5,400	£ 8,800 - £ 15,300	£ 15,400 - £ 26,550
Mid-terrace	1.3	£ 2,200 - £ 5,175	£ 4,400 - £ 8,550	£ 9,900 - £ 17,550	▨
	1.1	£ 2,200 - £ 5,175	£ 4,400 - £ 8,100	£ 9,900 - £ 17,550	▨
	0.8	£ 1,800 - £ 4,500	£ 3,300 - £ 5,850	£ 8,800 - £ 14,850	£ 15,400 - £ 26,550
Flats	1.3	£ 2,200 - £ 4,725	£ 4,000 - £ 7,650	£ 8,800 - £ 15,750	▨
	1.1	£ 1,320 - £ 4,000	£ 3,300 - £ 6,525	£ 7,700 - £ 14,625	▨
	0.8	£ 550 - £ 4,000	£ 2,200 - £ 5,175	£ 7,700 - £ 13,500	£ 12,800 - £ 22,950

Please note that costs are given as a range to reflect the various permutations of renewable technologies and sizes that could apply dependent upon the Heat Loss Parameter achieved in each case.

Appendix 4

Guidance on the fabric specifications and ventilation systems required to achieve the HLP performance requirements.

Table 5: Matrix for energy efficiency standards based on SAP calculations

Target HLP	**1.3**						**1.1**						**0.8**					
Dwelling type	Fabric Heat Loos U-value (W/m^{2}K)				Venti. loss		U-value (W/m^{2}K)				Venti. loss		U-value (W/m^{2}K)				Venti. loss	
	Walls	Floor	Roof	Win./ Doors	Mode*	Air perm.	Walls	Floor	Roof	Wind./ Doors	Mode*	Air perm.	Walls	Floor	Roof	Wind./ Doors	Mode*	Air perm.
Detached house	0.18	0.18	0.12	1.5/ 1.0	N	5	0.12	0.12	0.10	1.20/ 0.7	N	3	0.10	0.10	0.08	1.20/0.7	MVHR	1
End-terrace	0.26	0.22	0.14	1.7/1.0	N	5	0.18	0.16	0.10	1.40/ 0.7	N	3	0.14	0.12	0.10	1.2/0.7	MVHR	2
Mid terrace	0.28	0.22	0.14	1.7/1.0	N	8	0.26	0.20	0.14	1.70/ 1.0	N	5	0.20	0.16	0.10	1.5/1.0	MVHR	3
Flat	0.28	0.22	0.14	1.7/1.0	N	8	0.22	0.16	0.12	1.40/1.0	N	5	0.16	0.12	0.12	1.2/1.0	MVHR	3

* whether natural ventilation (N) / mechanical ventilation (M)/ mechanical ventilation with heat recovery (MVHR)

Notes:

1. The above figures are based on the following assumptions - use of accredited construction details to reduce thermal bridging (mandatory requirement to comply with Building Regulations), two sheltered sides, three intermittent extract fans for houses and two for flats where naturally ventilated.
2. Various permutations of fabric specifications and air permeability are possible to achieve the required HLP – the suggested values are based on good practice, best practice and advanced practice standards.
3. The HLP for flats is an average figure for a three story block of flats.
4. The % glazed area for the above dwelling types is ~ 15% of the floor area.
5. The units for air permeability are m^3/m^2/hr at 50pa.

Table 6: Matrix for energy efficiency standards based on SAP calculations - % reduction in DER

Target HLP	**1.3**	**1.1**	**0.8**	
Dwelling type			SAP default MVHR values - 66% efficiency, SFP = 2W/l/s	High efficiency MVHR with SFP<1.0 W/l/s
Detached	16.5%	24.8%	27.3%	33.15%
End-terrace	6.9%	17.1%	19.2%	26.02%
Mid terrace	2.6%	6.0%	8.9%	17.67%
Flat	4.1%	11.5%	12.0%	20.45%**

** 23.4% for ground floor, 17.5% for mid floor and 20.4% for top floor flats.

Appendix 5

Further information on Materials credits and Responsible Sourcing.

6.2 Material credits of the code

6.2.1 Environmental impact of materials

Building elements assessed under this issue are roof, external walls, internal walls (partitions and party walls), upper and ground floors (including separating floors) and windows. The maximum achievable score is 15 credits and the credit scoring system is indicated below. Credits are only awarded in multiples of whole numbers rounded down to the lower credit value (that is, 1.5 credits are rounded down to 1 credit)

Green Guide Rating	Credits	Weighted Score
A+	3	0.9
A	2	0.6
B	1	0.3
C	0.5	
D	0.25	
E	0	

Appendix 2 provides colour coded ratings for a range of specifications. For most building elements, the environmental benefits of timber are rather clear, with timber specifications largely falling into the ‘A+’ or ‘A’ rated category. The ratings for timber framed external walls depend on the type of external cladding, however, the commonly used specifications are again rated at the higher end of the scale, with an ‘A+’ rating for timber frame walls with softwood weatherboarding. However, masonry external wall and light steel framed constructions are equally close with the majority being A+ or ‘A’ rated. Similarly, for internal party walls and partitions, timber frame is ‘A+’ rated with masonry walls ‘A’ rated or worse. Hard wood or treated softwood windows achieve the ratings of ‘A+’ and ‘A’ depending on the type of paint used. Interestingly steel reinforced PVC-U windows also achieve an ‘A’ rating. All other window types including timber composite windows are rated ‘B’ or worse.

A key issue relating to the overall environmental impact of timber is the materials inherent link to deforestation and related environmental issues globally, which is not reflected in the Green Guide ratings. The sourcing of building materials is covered separately in the subsequent sections.

6.2.2 Responsible sourcing of building materials

A total of 6 credits are available in this section based on auditable third party certification schemes. Credits are awarded for each building element where 80% (by volume) or more materials comply. For each element, the number of credits achieved is calculated based on a graded scale (Tier 1 to 4) that reflects the rigour of the specific certification scheme. Tier 1 (scoring higher credits) includes certain timber certification and re-used materials, that is, materials that can be extracted from the waste stream and used again without further processing. Timber certification schemes that fall into this category are FSC, CSA, SFI and PEFC. There are currently no schemes allocated to Tier 2. Other timber certification schemes fall into Tier 3 and include MTCC, Verified, SGS and TFT. For all other materials compliance can be demonstrated for Tier 3 through EMS (Environmental Management Systems) certificates at process and/or extraction stage, or only for process stage for Tier 4 compliance. As a base requirement for compliance all timber used in the development must be legally sourced.

A simplified description of the credits achievable is included below. Building elements include frame, ground floor, upper floors, roof, external and internal walls, foundation and staircase.

	Timber framed building	Masonry/ other modern methods of construction
High range credits	Timber certified under certification schemes (minimum 80% by volume in each building element).	All building elements have more than 80% re-used materials (by volume). Materials reused in-situ are excluded.
Mid-range credits	Timber certified under the FSC, CSA, PEFC or SFI certification schemes and all other materials have EMS certificate at process and extraction stage (such that in total at least 80% of materials in each building element comply)	Bricks, stone, concrete (including blocks tiles etc.), glass, metals, plasterboard, plastic and composites have an EMS certificate[a] from manufacturers at process[b] and supply chain[c] stages. Any timber used is certified under FSC, CSA, SFI or PEFC certification schemes.
Low end credits	Timber certified under MTCC, SGS or TFT certification schemes (minimum 80% in each building element)	Bricks, stone, concrete (including blocks tiles etc.), glass, metals, plasterboard, plastic and composites have an EMS certificate from manufacturers at process stage. Any timber used is certified under MTCC, SGS or TFT certification schemes.

[a] *Suppliers are required to have either of the following for their products at process and/or extraction stage as relevant*

- *ISO 14001 certificate*
- *EMAS certificate*
- *For SME's (generally companies of less than 30 staff) confirmation that the company EMS is structured in compliance with BS8555 2003 (or equivalent) and the EMS has completed phase audits one to four as outlined in BS8555.*

[b] *Process stage is considered to be the stage at which either the product or the components of a product are processed e.g. brick, cement, metals, glass, etc. or the reclamation of materials such as PFA.*

[c] *Supply chain cover all the major aspects of processing and extraction involved in the supply chain of the end product. Extraction is considered to be the stage of extraction of the raw materials e.g. clay, aggregate, hematite, bauxite, stone etc.*

In general, timber frame buildings with timber certified under Tier 1 schemes will score the highest credits. The supply chain for certified timber is now well established and a number of suppliers offer products with FSC, PEFC or SFI certification at little or no cost premium. In comparison masonry buildings are likely to score only mid-range credits even where relevant EMS certification is available at both process and extraction stage for all building materials. This may prove onerous both in terms of the paperwork involved and limited suppliers offering certification that cover the products life cycle. For most schemes, the score is more likely to lie at the lower end of the scale with EMS certification at process stage for a limited range of materials. Having said that the materials credits within the Code are weighted poorly, and therefore the loss of credits may not be such an issue for Code levels 3 and 4. For higher Code levels, however, this may imply having to comply with other costly or technically challenging issues to achieve the required overall score.

For the purposes of the analysis in this report, we have assumed that the required material credits can be achieved at no cost, albeit that, in the short term, contractors may incur some additional expenditure associated with achieving higher supply chain performance.

6.2.3 Responsible sourcing of finishing materials

The methodology for achieving credits under this issue is as mentioned in the section above. A total of 3 credits are available. The following finishing elements are included – stair, window, external and internal door, skirting, paneling, fixed furniture, fascias and any other significant use.

Appendix 6

A detailed breakdown of carbon dioxide emissions by construction and building type.

concrete intensive construction types as the same construction methods are assumed for both house types. The external and partition walls create the largest difference in the emissions between the two construction types. The large amounts of timber used in the timber intensive construction creates a carbon sink which ultimately lowers the overall emissions for this type of construction by as much as a fifth compared to the masonry alternative.

Table 13: Detailed breakdown of carbon emissions by construction and building type

House type and component	**t/CO2e**							
	end terrace		**mid terrace**		**detached**		**flat**	
	timber	concrete	timber	concrete	timber	concrete	timber	concrete
external and dividing walls	-3.3	8.4	-2.5	4.9	-4.5	13	-1.9	5.7
internal walls	-0.06	0.6	-0.06	0.6	-0.22	2.04	-0.08	0.77
foundations	0.9	0.9	0.9	0.9	1.6	1.6	0.7	0.7
windows	0.07	0.07	0.06	0.06	0.15	0.15	0.11	0.11
exterior doors	-0.007	-0.007	-0.007	-0.007	-0.008	-0.008	-0.003	-0.003
roof	1.6	1.6	1.6	1.6	2.9	2.9	0.96	0.96
concrete slab	5.2	5.2	5.2	5.2	5.7	5.7	2.3	2.3
floors and ceilings	-0.4	4.3	-0.37	4.3	-0.6	6.9	-1.3	9.6
Totals	**4**	**21**	**4.8**	**18**	**4.96**	**32.4**	**0.7**	**20.1**

6 Environmental Impact of Materials

The extraction, manufacture, transport and disposal of buildings materials has a detrimental impact on the environment, including contribution to global warming, consumption of scare resources, and release of toxic chemicals into the ecosystem. Quantifying these for a range of material and construction types can provide a basis for specifying materials that minimise environmental damage, although local issues and factors should gain precedence (such as water extraction for manufacture in areas with severe water shortage).

6.1 Brief description of Green Guide ratings

The Green Guide ratings provide a basis for a comparative assessment of environmental impact of different construction specifications. The BRE ‘Environmental Profiles’ database is adopted as the basis for such ratings. The profile relates to the environmental burden of building components or materials across twelve key categories including climate change, fossil fuel depletion, ozone depletion, freight transport, human toxicity, waste disposal, water extraction, acid deposition, ecotoxicity, eutrophication and mineral extraction. The Green Guide methodology takes a cradle to grave approach over a 60-year building life taking into account maintenance and refurbishment over this period and demolition at the end of its life. It expresses the relative impacts on a simple environmental scale running for ‘A+’ (minimal) to ‘E’ averaged across all twelve environmental impact categories.

Appendix 7

Definition of thermal mass

Appendix A

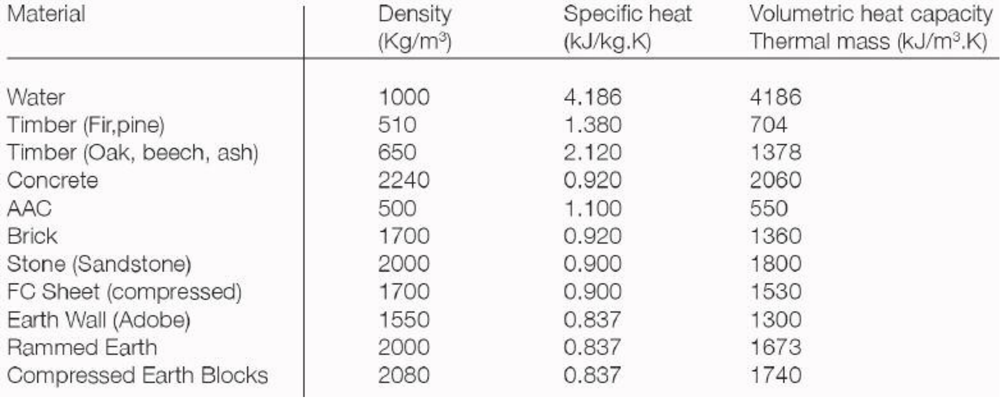
Thermal Mass

Thermal mass is the ability of a material to store heat. The properties that determine the thermal mass of a material are:

- Specific Heat Capacity
- Density
- Thermal Conductivity

The specific heat capacity of a material is the amount of energy required to raise the temperature of 1kg of a material by 1°C. Multiplying this by the density of the material gives the volumetric heat capacity, which is the amount of energy required to raise the temperature of 1m^3 of a material by 1°C.

$$\underset{(kJkg^{-1}K^{-1})}{\text{Volumetric Heat Capacity}} = \underset{(kgm^{-3})}{\text{Density}} \times \underset{(kJkg^{-1}K^{-1})}{\text{Specific Heat Capacity}}$$



Material	Density (Kg/m^3)	Specific heat (kJ/kg.K)	Volumetric heat capacity Thermal mass (kJ/m^3.K)
Water	1000	4.186	4186
Timber (Fir,pine)	510	1.380	704
Timber (Oak, beech, ash)	650	2.120	1378
Concrete	2240	0.920	2060
AAC	500	1.100	550
Brick	1700	0.920	1360
Stone (Sandstone)	2000	0.900	1800
FC Sheet (compressed)	1700	0.900	1530
Earth Wall (Adobe)	1550	0.837	1300
Rammed Earth	2000	0.837	1673
Compressed Earth Blocks	2080	0.837	1740

Thermal Conductivity describes the ability of a material to absorb and emit heat. The higher the thermal conductivity the quicker the material will absorb and emit heat. The Thermal Conductivity is a measure of the quantity of heat transmitted through 1m of material with a 1°C temperature difference across the material and is measured in Wm^{-1}K.

External Mass

Thermal mass in the outer envelope of the building (walls and roof) can be used to store a proportion of the energy from high solar gains during the day, and help to dampen fluctuations in the outside air temperatures, then slowly releasing them through to the indoor environment. This delays the occurrence of peak indoor air temperatures by up to several hours. This is useful if the peak can be shifted to the unoccupied period in the summer. Thermal diffusivity is used to describe how fast heat travels through a material and can be calculated using the following equation:

$$\text{Diffusivity } (m^2s^{-1}) = \frac{\text{Conductivity } (Wm^{-1}K^{-1})}{\text{Density} \times \text{Specific Heat Capacity } (kgm^{-3})\ (kJkg^{-1}K^{-1})}$$

The amount of time taken for a material to absorb and then re-release or for heat to be conducted through a material is described by the time lag. The time lag between the outside and inside peak temperature can be calculated using the following:

$$\text{Time Lag} = \frac{\text{thickness (m)}}{\sqrt{\text{(diffusivity)}}}$$

Internal Mass

Including interior mass within a building's internal structure (floors, partitions, etc) creates a heat sink into which internally generated heat can be absorbed and stored during the occupied period (Russell & Surendran, 2001). During the unoccupied period the mass can then be cooled using night cooling (Kolokotroni et al., 1999).

Appendix 8

Construction details of comparative models.

Construction

The base condition modelled was a lightweight timber frame to typical current construction methods with a ground bearing concrete slab. This slab was modelled initially with a carpet covering, and then with a tiled floor to improve the exposed thermal mass. Further sequential thermal mass was then added into the structure through double plasterboarding all walls, and also by using double cementboard (suitable for wet areas) to all walls. These constructions were then compared to the standard new-build masonry structure.

Five construction types were modelled:

- Timber frame with carpet flooring: Refer to Figure 2
- Timber frame with tiled ground floor: Refer to Figure 3
- Timber frame with tiled ground floor and double plasterboard to walls: Refer to Figure 4
- Timber frame with tiled ground floor and double cementboard to walls: Refer to Figure 5
- Standard New-build Masonry Construction: Refer to Figure 6

Within the standard new-build masonry construction, plasterboard is affixed to the blockwork using the current industry standard of 'dot and dab' method. This creates an airgap between the plasterboard and blockwork, reducing the thermal conductivity through the element resulting in the structure responding in a less 'heavyweight' manner. In order to model this, a 5mm air gap was introduced between the plasterboard and block walling, over 50% of the wall area. To incorporate this into the IES model, a mean of the thermal conductivity, specific heat capacity and density was used to represent the thermal performance of the dot and dab method.

Figure 2 Timber frame with carpet flooring
Note: Internal walls are assumed to be stud partitioned

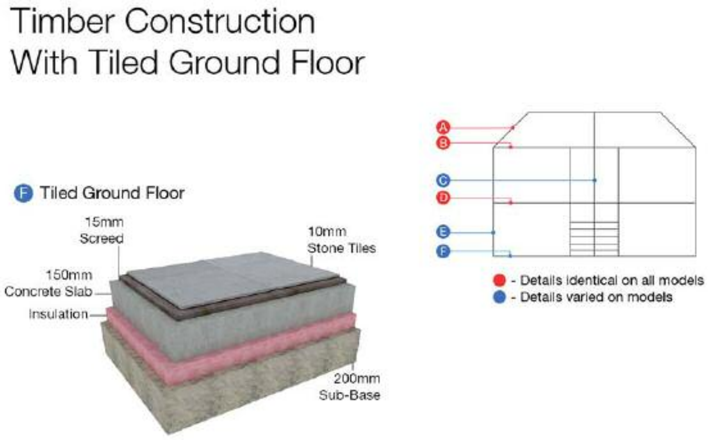


Figure 3 Timber frame with tiled ground floor
Note: Other elements identical to 'Timber construction with carpet flooring' (Figure 2)
Note: Internal walls are assumed to be stud partitioned

Figure 4 Timber frame with tiled ground floor and double plasterboard to walls
Internal stud walls have double plasterboard to faces.
Note: Other elements identical to 'Timber construction with carpet flooring' (Figure 2)

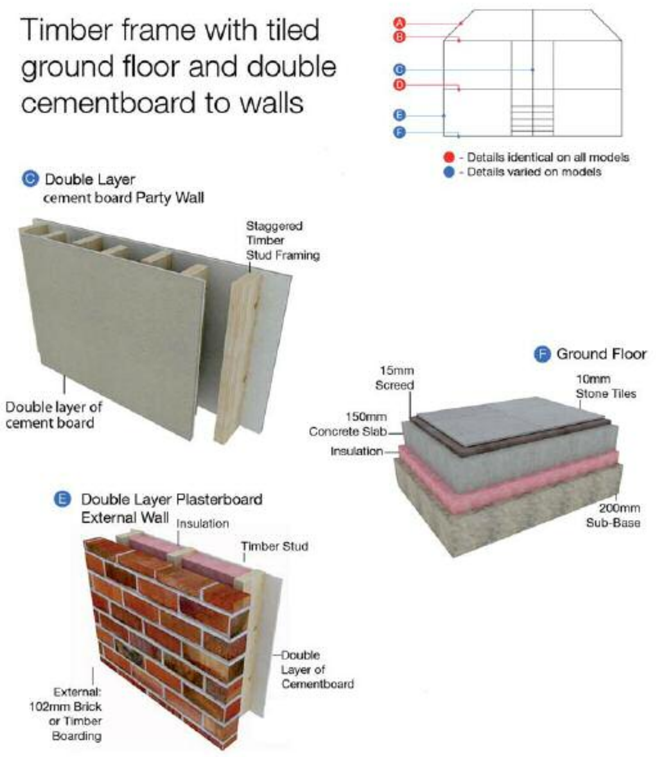


Figure 5 Timber frame with tiled ground floor and double cementboard to walls
Internal stud walls have double cementboard to faces (suitable for wet areas).
Note: Other elements identical to 'Timber construction with carpet flooring' (Figure 2)

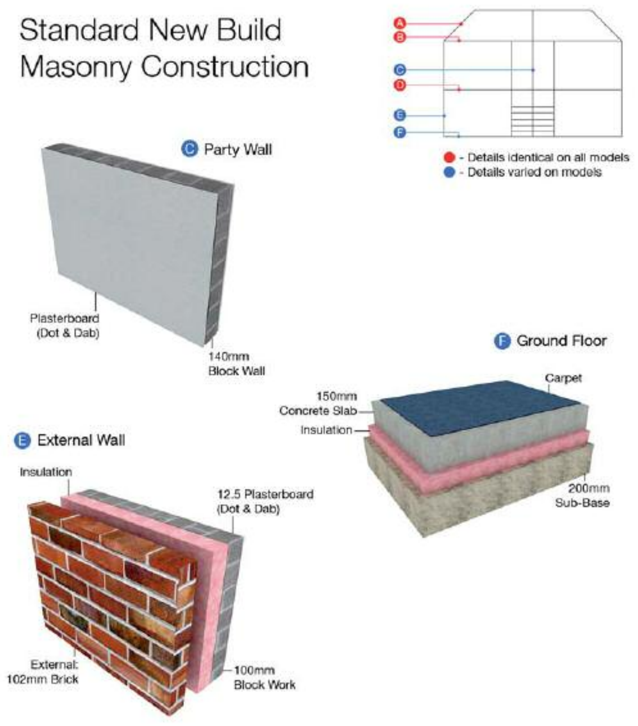


Figure 6 Standard new build masonry construction
Note: Internal walls are assumed to be stud partitioned
Note: Other elements identical to 'Timber construction with carpet flooring' (Figure 2)

UKTFA QUALITY ASSURED

wood for good

FRONT COVER IMAGE: 'The Deck' at Runcorn Courtesy of Prestoplan for Taylor Wimpey

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