# Sustainable Housing

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# Abstract

There is a large amount of information available on sustainable housing but the information is somewhat fragmented and often contradictory. The overall objective of this thesis has been to construct a review of current thinking on sustainable housing, identify some key area's where there are current debates and to make a contribution to these debates. The two area's where this thesis hopes to make a contribution are firstly; the debate on standards and metrics that should be applied to achieve sustainable housing, and secondly; the debate on the impact of thermal mass, ventilation and insulation on sustainable housing across the range of UK climates and occupancies.

The focus of the initial phase of the project was to gain a historical perspective and an understanding of current thinking on sustainability in housing. Chapter 1 gives a definition of sustainability in housing, a review of the broad scope of factors which have an influence on sustainable housing, and also provides a review of historical and current initiatives and best practice examples. Chapter 2 continues to document current thinking through the construction of concise summaries of UK and European standards and metrics in sustainable housing.

Having gained an understanding of the current standards, metrics and best practice examples, a comparative analysis was then carried out. Two different analysis methods were used and these are documented along with the results in chapter 3. The first method used was to construct a comparison table documenting the approaches taken to sustainable energy use. This table allowed area's of consensus or disconnect to be highlighted. The second method used was to calculate a range of sustainability metrics to allow a quantitative comparison to be made. The results of the analysis are discussed in chapter 4 and conclusions and recommendations are presented. The recommendations include improvements to the current assessment and scoring methods and metrics. The need for further investigation into the role of thermal mass, ventilation and solar gain in sustainable housing is identified. This investigation is the focus of the second half of this project.

The conflicting views on thermal mass, ventilation and solar gains are further explored in chapter 5 and a simple calculation model is developed and used to illustrate the role of these parameters and the importance of insulation standard, climate and occupancy. An ESP-r model is then developed as the basis of a more comprehensive, rigorous and detailed evaluation.

ESP-r is used to investigate the impact of thermal mass, insulation, solar gain and ventilation on heating and cooling demands in housing across UK climates and for a wide range of occupancy scenarios. The methodology used and the results generated are given in chapters 6 and 7. The results are discussed in chapter 8 and an explanation is given for the conflicting views on the applicability of thermal mass. The relative importance of the various parameters is quantified and a matrix presented showing the appropriate use of thermal mass for the example building used in this study. It is suggested that building energy simulation be used at the design stage of any proposed new build or refurbishment.

Overall conclusions and some suggestions for future work are presented in chapter 9.

# Contents

# Chapter 1:

# Introduction to sustainable housing

### 1.1 Sustainability in housing

Sustainability can be defined as the ability to meet the needs of today without compromising the ability of future generations to meet their needs. [1]

In this thesis sustainable housing is defined as housing that meets the needs of today's people and does not compromise the ability of future generations to meet their needs.

The needs of today's people are diverse and include safety, physical and mental health, privacy, entertainment, education, socialising, comfort, adaptability, access to workplace, transport inc. bicycles, utilities including clothes drying spaces, availability of garden space, access to foodstuffs and other commodities and of course affordability.

These needs must be satisfied without compromising the needs of others.

Future generations should not be compromised. Through all the phases of housing (raw material procurement, construction, operation, renovation and demolition) the goal is to avoid pollution, minimise the use of non-renewable resources, avoid waste, and continue to meet the changing needs of the future generations.

Today in the UK our resource usage if projected onto the worlds population would require 3 times the earths available natural resources to sustain it [2].

The EcoHomes standard [3] has been developed in the UK by BRE to drive sustainability improvement in housing. The key elements in the Eco-homes standard are highlighted below and again serve to illustrate the broad scope of factors.

The EcoHomes scores are allocated in 7 categories:

**1. Energy**
a. Reduction in $CO_2$ emissions.
b. Improvement to fabric of building.
c. Provision of secure drying space.
d. Provision for eco-labeled white goods.
e. Provision of low energy external lighting systems.

**2. Transport**
a. Access to public transport.
b. Provision of a cycle store.
c. Proximity to local amenities.
d. Provision for home office.

**3. Pollution**
a. Reducing ozone depleting substances.
b. Specifying low $NO_x$ emitting boilers.

**4. Materials**
a. Sustainable managed timber.
b. Storage of recyclable waste.
c. Obtaining an A-rating from BRE Green Guide to Housing Specification [ ].

**5. Water**

**6. Land use and ecology**
a. Ecological value of site.
b. Change of ecological value.
c. Building footprint.

**7. Health and wellbeing**
a. Provision of adequate day-lighting.
b. Improved soundproofing.
c. Provision of open space.

Sustainable housing needs to comprehend the full scope of sustainability and address more than just the resource consumption for heating and lighting during use of the house. The diagram below illustrates the broad scope of factors associated with sustainability in housing.

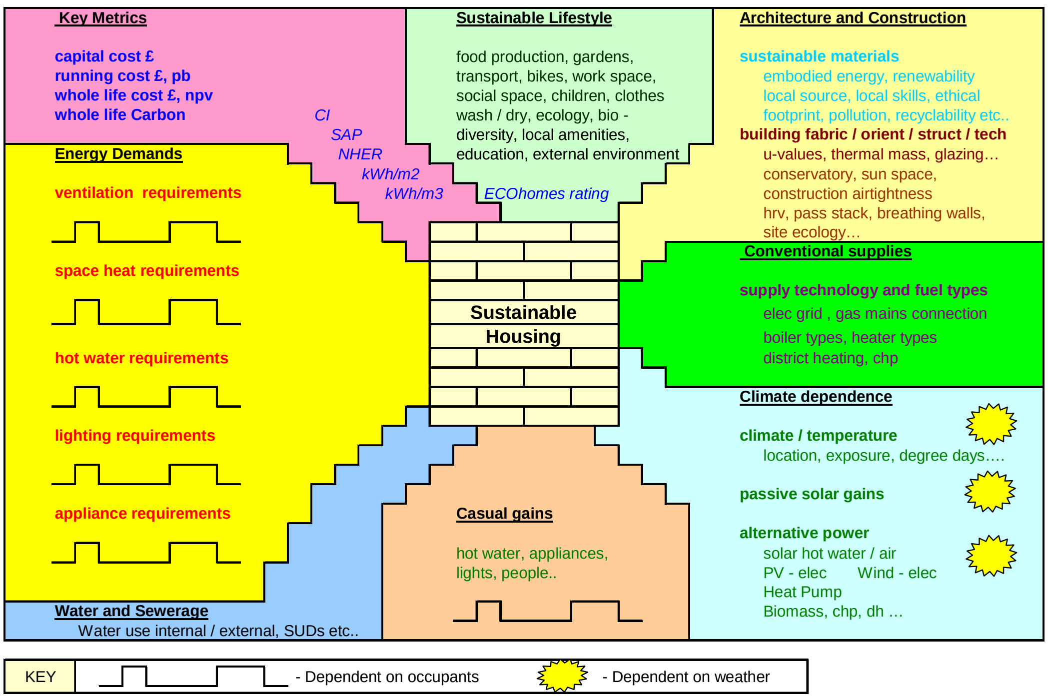


Figure: Factors influencing sustainability in housing.

**1.2 History, current initiatives and examples of sustainable housing**

Efforts towards sustainability are now the subject of global governmental focus however many groups and organisations have been pursuing sustainable communities and housing for many years.

The FIndhorn Community [4] is in a rural setting near Inverness in the north of Scotland. It was founded in the 1962 and has been championing sustainability since its beginning. The community has followed the path of using sustainable materials (primarily timber frame with timber cladding) with low embodied energy, advanced insulation standards and passive and active renewable energy. The details of the timber frame construction method including the breathing walls are documented in the book ‘Simply Building Green’ [5]. The community has a gas district heating scheme, a wind turbine, solar hot water heating and a ‘living garden’ sewage system. The community promotes the breathing wall construction method as a way to achieve a more natural and healthy environment. Although the principal building method used is timber frame there are also successful straw bale houses and there is a less than successful earth-ship, the earth-ship was too cold for a dwelling and now houses the district heating boiler. Many of the buildings have grass roofs which support an ecosystem. The community is a co-operative and supports several businesses including a solar hot water heating company. The community has a spiritual ethos and runs spiritual courses as well as courses on sustainability and renewable energy. Findhorn is a part of the Global Eco-village Network (GEN).

The Centre for Alternative Technology (CAT) in Powys, Wales was founded in 1972 and has the mission ‘to inspire, inform and enable people to live more sustainably’. As well as a visitor centre with demonstrations and courses on low energy housing and renewable energy, CAT provides a consultancy service and has produced many technical publications on sustainable living, sustainable materials and sustainable housing. In general the stance taken by CAT is that the construction phase embodied energy of a building is significant and that low embodied energy is of increasing importance as the energy in use in housing is reduced by improved insulation, lighting and appliances or offset by renewables [6]. It is stated that the typical house energy consumption in use is around 10-15 times the energy consumed in construction but that for a modern well insulated house this reduces to a factor of 3. CAT promotes the use of locally produced timber as a replacement for energy intensive heavyweight materials and states that the cement industry alone accounts for 10% of the worlds CO2 emissions. The total of construction and materials energy for a timber frame house is given as 58,500 kWh compared to 119,000 kWh for a masonry construction [6]. CAT recognise that to take full advantage of solar gains the building must have thermal mass sufficient to avoid overheating which would trigger ventilation cooling which would effectively waste the passive solar energy. CAT states that the lightweight timber framed house might have 4 tonnes of plasterboard in it, inferring that this may be sufficient. CAT also makes the points that most heat transfer takes place in the first half inch of walling and that solid floors when covered by carpeting do not contribute to thermal mass. CAT have been consultants on the Hockerton Housing project which is reviewed later in this section.

Brenda Vale is Professor of architectural technology and her husband Robert Vale is senior research fellow at the University of Auckland New Zealand. Prior to taking up the posts in New Zealand in 1996 they were leading green architects in the UK. The Vales approach to sustainable housing has been to use high levels of insulation (with great attention to detail to avoid thermal bridging) and air-tightness in combination with high thermal mass and mechanical ventilation with heat recovery to minimise energy used for space heating. Their Cresswell Road houses in Sheffield were completed in 1993 and had u-values around 0.2 W/m2K, their next housing project was the Autonomous Urban House in Southwell, Nottinghamshire which had u-values around 0.1 W/m2K, both were featured in the 1996 EEBPp ‘Review of ultra-low energy homes’ [7]. Both buildings were of a masonry construction, the rationale being that the higher embodied energy for the thermally massive construction is more than compensated by the lower energy required in use.

The Vales document their design considerations, theoretical analysis of options, implementation experiences and experience of building performance in use for the Southwell Autonomous house in their book ‘The New Autonomous House’ [8]. Chapter 4 of the book ‘Theoretical analysis of the technical options’ gives the basic calculations used to justify the selection of a super-insulated, airtight, mechanically ventilated (with heat recovery), high thermal mass construction. It is worth noting that the Autonomous House was not oriented or designed for maximum solar gain due to site constraints, the conservatory was used as a buffer space to minimise heat losses and optimise ventilation. The Vales calculations are reviewed in section 2 of this thesis. The house has a wood burning stove for use as backup heating only. It also has a composting toilet, drinking water capture and grey water recycling with the plant for these housed in the cellar which is accessed through the conservatory. The performance in use of the house is documented and it achieves 6.4 kWh/m2 pa space heating and 9.6 kWh/m2 pa electrical demand (including electrical water heating). The electrical demand is completely offset by a PV array. The Vales experiences were the basis of EEEBPp general information report 53 (GIR53) 'Building a sustainable future' [9] which details the 'Zero CO2', 'Zero Heat' and 'Autonomous' standards for sustainable housing, this is discussed in more detail in the section on UK best practice guidelines.

After the 'Autonomous House' the Vales next project was the Hockerton Housing Development, again near Nottingham [10,11]. The Hockerton development was on land belonging to Nick Martin who was the builder contracted to construct the Autonomous house. This 5 dwelling project carries the high thermal mass, super-insulation, mechanically ventilated concept even further with very thermally heavy concrete construction and earth sheltering. Hockerton is oriented to fully exploit solar gains with only south facing triple glazed windows into a double glazed conservatory. The south façade which incorporates the conservatory has an overall u-value of 0.2 W/m2K [ 8]. Hot water heating is through air to wet heat pump from a high level in the conservatory to a large highly insulated storage tank, the heat pump is controlled to operate only when the conservatory is at a high temperature (sunny winter days). A wind turbine installed for electricity supply. The Hockerton Houses are reported to require only occasional use of radiant fires for space heating, it is also reported that some of the homes have installed wood burning stoves in the conservatory space for occasional use. Hockerton was completed in 1998. The Vales received the first 'green building of the year' award and the UN 'global 500 award for environmental achievement' for their contributions to sustainable housing.

In parallel in the mid 1990's architect Bill Dunster constructed his 'Hope House' as a passive solar house (below) and developed outline plans for a solar village with roof gardens [12]. Dunster later partnered with Chris Twinn of Ove Arup to refine the building physics of a proposed zero zero fossil energy development. These initial concepts ultimately led to the realisation in partnership with Bio-regional, Sutton Council, the World Wildlife Fund and the Peabody trust of the BedZED (Beddington Zero Energy Development) as a model of a carbon neutral urban development. The development covers 82 homes, 3000m2 work facilities, transport and community facilities and was completed in 2002. The design, development and performance in use of the BedZED project is comprehensively documented [13,14,15].

BedZED design concept has followed similar principals to the Vales 'Autonomous House' and the 'Hockerton Housing' but has extended and developed these principals into a high density urban context. The buildings are southerly oriented with conservatories, super-insulated (0.1 u-values), high thermal mass concrete airtight construction with passive stack heat recovery ventilation. Design decisions were made based on minimising the ecological footprint, with BedZED target being to live within the 2.18 hectares per person that is deemed sustainable [13,14,15]. The method used was the BRE Environmental profiling system which uses life cycle assessment methodology and assigns 'Ecopoints' to allow informed decisions. There was a large use of recycled material. Each dwelling has access to a garden with many of the gardens integrated into the roof spaces, inaccessible roof spaces are covered with a sedum (hardy low maintenance succulent plant) roof which supports its own eco-system. There is a wood burning CHP system (gasification, charcoal producing CHP plant) providing electricity and heat for hot water, there are PV systems integrated into the conservatory which provide electricity for electric vehicles.


Dunsters Hope House (left) and BedZED (right)

The BedZED development hosts a visitor centre and the offices of BioRegional environmental group and Dunster Architects ZEDfactory organisation. Many of the design principals and component specifications are documented in the ZEDfactory publication ‘From A to ZED’ [15].


BedZED

The INTEGER organisation (Intelligent and Green) which is formed through the collaboration of building professionals designed and built the ‘INTEGER Millennium House’ [16] on the BRE campus at Garston, near Watford. The house was completed in 1997. The INTEGER concept is to utilise environmental design and intelligent technologies. The millennium house has a south facing unheated conservatory, has a partly earth sheltered north wall, has pre-cast concrete lower walls and floor slab on pile and beam foundations and timber frame upper walls. The construction utilised pre-fabricated walls and bathroom and shower room pods and incorporates plasterboard battened off the walls to provide service voids. Pre-fabrication was seen as a way of saving cost and also speeding up on – site construction time, timber frame and lightweight construction has an advantage in the energy required to transport the pre-fabricated units. The insulation level is stated as being half the building regulation maximum or around 0.2 W/m2K. The large conservatory is used as a rainwater collection source. The energy supply incorporates a ground source heat pump, a 1.8m diameter wind turbine, solar hot water heating and PV. The supply technologies, heating, hot water and automated ventilation and shading are controlled centrally.

A second INTEGER project, this time targeted at low cost social housing, is the development of 27 dwellings at Alpine Close in Maidenhead [17]. This development again utilised pre-cast concrete ground floor, timber frame construction with a 0.2 W.m2K insulation level and pre-fabricated pods for the serviced areas. In this case a sedum roof was utilised. Passive stack ventilation is installed. Light pipes are used to give enhanced daylighting. The power supply incorporates PV and solar water heating. Water systems incorporate rain water harvesting for garden use and grey water recycling for toilet flushing. The development has received National Homebuilder and Civic Trust awards.

The buildings research establishment (BRE) in Garston, near Watford caries out extensive research into sustainable housing and is the source of the UK guidelines. There are several houses on the Garston site which are used to pilot and investigate options.

The University of Nottingham School of the built environment hosts the Marmont Centre for Renewable Energy, the Institute for building technology, the David Wilson Millenium Eco-house and the Jubilee Campus. The David Wilson Eco-house is a four bedroom house of brick and block construction which will be occupied by research students and used in research into domestic sized renewable energy systems, features incorporated so far include solar chimney for ventilation / heating, light pipes, PV, solar hot water heating and a conservatory.

The UK Association of Environment Concious Builders (AECB) [18] is an organisation established in 1989 to promote sustainability in all scales of building. Its aims are to promote healthy sustainable products, encourage projects that enhance the environment, provide information and guidance about products, methods and projects. Membership of the AECB includes subscription to the 'Building for a Future' publication [19] from the green building press who also publish the 'Green Building Bible' [20] annually (since 1999) and provide an online directory of green building products called GreenPro [21]. The Green Building Bible provides general guidelines on primary embodied energy for a variety of common building materials.

The Green Building Bible article on housing design by John Shore [22] recognises that "there are two main schools of thought in design of sustainable buildings, Timber frame, with 300mm thick walls filled typically with cellulose-based insulation and clad externally in timber or slate produces a warm, strong, light-weight and adaptable structure with little thermal mass which only needs minimal foundations and very little heating. Such a building can be designed so that most of the structure is originally bio-mass based, shading (blinds, shutters or plants) can be used to prevent summer overheating. For buildings which are constantly occupied, it can be argued that thermally massive construction based on the use of earth, rock or concrete is also ecological and desirable. With heavy-weight buildings the construction time, skills and cost, incorporation of sufficient levels of ecological insulation and the need for a sustainable heating system also have to be considered." Overall Shore's vision is of "timber frame floor, wall and roof panels, prefabricated locally to high standards / the majority of construction being complete in a matter of weeks. In winter a 1kW heating system is all that will be required / the planet can stop holding its breath".

David Finney recently reported in 'Building for a Future' on his experiences of design, building and living in his own high mass and low mass low energy homes [23]. The high and low thermal mass houses are built to approximately the 2002 building regulations (England) with walls having a U-value of 0.35 W/m2K. He sites references from 1974 and 1980 and states that "computer simulation has suggested that, overall, a high inertia house will use at least 10% more energy, dependent on the level of insulation". He reports his experience that in the high mass house "more fuel was clearly required to 'charge up' and keep the high thermal capacity walls 'filled' if they were not to act as cold sinks".

John Gilbert architects of Glasgow and Gaia architects of Edinburgh are members of AECB and showcase their environmental housing projects and their thoughts on sustainability on their web-sites [24,25]. Gaia champion the 'breathing wall' construction as a healthy and sustainable option similar to Findhorn. The John Gilbert Partnership has used innovative approaches to sustainable housing including ground source heat pumps utilising mine water.

The Green Guide to Housing Specification from BRE [26] which was first published in 2000 and is now in its third edition provides environmental impact ratings based on life cycle assessments of the materials themselves and also the assessment of the environmental impacts in use of the materials including repair, replacement and required maintenance. The highest weighted factors in the ratings are the climate change and fossil fuel depletion impacts, other factors are ozone depletion, freight transport, human toxicity, waste, water, acid, eco-toxicity, eutrophication ( water pollutants that cause algal blooms)), summer smog and minerals extraction. Ratings are given for each category and also a summary rating (A,B,C). The A ratings are generally given for more lightweight constructions i.e. aerated concrete blocks or timber frames for walls, plywood decking ground floors etc. with heavyweight components, plastics or non-local timber requiring high transportation performing worse i.e. dense block-work in walls, PVC weatherboarding, polymer resin slates. The Green Guide to

Housing specification is to be used in conjunction with the Eco-homes standard which is covered in the next section.

Self building of homes is an area in which non traditional approaches have been taken and a significant part of the self build movement has had a focus on sustainability. This is in part due to the opportunity in self build for the house owners to be involved in the pre-build specifications as opposed to the build for sale approach of most commercial house-builders. Also many self builds are in more isolated situations where the economics are more attractive for alternative approaches. The ‘Self Build’ magazine and the book ‘All about Self-build’ [27] give many examples of green buildings and green building services. In ‘All about Self-build’ there are sections relating to the integration of renewables and also calculation assessing the impact of insulation and ventilation on heating costs. The European Passive-house’ standard is also discussed in the book.

The ‘Passive House’ standard has been the subject of EU THERMIE project BU/0127/97 ‘Cost Efficient Passive Houses as European Standards’ (CEPHEUS). More than 1000 houses have been built to the passive house standard, the CEPHEUS project has monitored 250 passive houses across Switzerland, Germany, Austria, France and Sweden [28]. The passive house target is to keep total final energy demand for space heating, domestic hot water and household appliances below 42 kWh/m2 pa and space heating below 15 kWh/m2 pa. The passive house specification calls for u-values of 0.1 W/m2K, airtight construction and mechanical ventilation with heat recovery. There is no specification relating to thermal mass, passive houses have been realised in both thermally light and thermally heavy constructions.

Several Passive Houses are included in the International Energy Agency (IEA) Sustainable Solar Housing demonstration house brochures [29]. The demonstration houses have a range of constructions from thermally light timber frame, through light frame with concrete flooring to the heaviest which have multiple high mass elements. In general the use of increased solar mass in these demonstration houses appears to be driven by the requirement for night cooling by cross ventilation in summer. The IEA demonstration houses in Tuusniemi in Finland (lat 62N) are entirely lightweight construction. The houses in Goteborg in Sweden, Thening in Austria and Dinkton in Switzerland have thermally low mass constructions with high mass concrete floors (the Thening house also has underground air pipe ventilation cooling). The Hanover, Germany terrace housing has low mass external walls but high mass internal and cross walls. The southern Switzerland demonstration house has a thermally massive construction similar to the UK Zero Heating standard and the BedZED, Hockerton and Autonomous houses. In general the amount of thermal mass increases the more southerly the location driven by summer cooling.

# Chapter 2:

# A review of current standards and metrics in sustainable housing

Legislation, standards and guidelines that relate to sustainable housing in the UK and Europe are reviewed in this section.

### 2.1 UK Building regulations

The minimum standard for new housing is established through the building regulations. The government recently issued a draft proposal for new regulations to come into force in 2005. The summary of the proposed Scottish 2005 regulations [30] which are key to sustainability are reviewed below. Section 3 'Environment' and in section 6 'Energy' contain the relevant regulations.

In 'Precipitation' (section 3.1), wall construction types given as examples all include vapour barriers (breathing wall construction is not shown). BRE, EEBPp, EST and BS documents also specify a vapour barrier in the case of timber frame construction.

In 'Heating' (section 3.13) Whole house central heating is stated to be almost essential in combating problems such as condensation and mould growth.

In 'Ventilation' (section 3.14) the guideline is summarised in the following table.

| Space | Primary Ventilation | Trickle Ventilation |
|---|---|---|
| Apartment | 1/30$^{th}$ floor area | 8000mm2 (house average >6000mm2) |
| Kitchen | Extract 30l/s above hob or Extract 60l/s or PSV | 4000mm2 |
| Utility | Extract 30l/s or PSV | 4000mm2 |
| Bath/Shower room | Extract 15l/s or PSV | 4000mm2 |
| Toilet | 1/30$^{th}$ floor area or Extract 3 ac/h | 4000mm2 |

The guidance given on mechanical ventilation is that **'**Continuously operating balanced supply and extract systems were popular in early nineties but their increasing use has been limited due to sustainability considerations. Simpler mechanical systems are being used to augment or complement the natural ventilation'.

Acceptable mechanical ventilation systems are given as '1. Continuously operating mechanical supply and extract with heat recovery (HRV) in accordance with BRE Digest 398 [31]. 2. Continuously operating mechanical extract ventilation in accordance with BRE Digest 398. 3. Extract vents in 'wet' rooms. 4. Mechanical input ventilation to supplement natural ventilation. '

BRE Digest 398 states that 'for MVHR or MEV to be economic the dwelling air-tightness needs to be below 0.2 ach in masonry and somewhat less in timber constructions. 0.7 ach is probably typical. The 0.2 ach requirement is equivalent to 4 ach at 50 Pa. The total MV system vent rate should be equivalent to between 0.5 and 0.7 ach less an allowance for background infiltration if desired. Significantly higher rates perhaps between 2 and 5 ach will be present in the extract rooms (normally the wet rooms). Supply air is set to 90-95% of extract to depressurise dwelling and minimise interstitial condensation risk. Trickle ventilation is needed with MEV to balance the extract. If the system is switched off windows should be opened.

Passive stack ventilation should be installed in compliance with BRE IP 13/94 which specifies duct sizes, materials and controls, there is no requirement for heat recovery on PSV systems.

In ‘Condensation’ (section 3.15) the guideline is that ‘Every Building must be designed and constructed so there is no threat to the occupants health or building fabric as a result of surface or interstitial condensation’ Reference is made to BS 5250: 2002 ‘British Standard Code of Practice for the control of condensation in buildings’ for correct construction techniques. BS 5250 states that to avoid condensation 0.5 to 1.5 ac/h recommended. All examples given of timber frame construction include vapour barriers, no breathing walls.

In ‘Day-lighting’ (section 3.16) guidance is that a glazed area of > 1/15$^{th}$ of the floor area or room is required in a habitable room, the kitchen is not deemed habitable.

In ‘Building Fabric – Limiting Energy Use’ (section 6.2), the guidance is that ‘Every Building should be designed and constructed so the insulation envelope resists thermal transfer’. Three possible approaches to meeting the guidelines during building design are allowed;

1. The elemental method
2. The target-U method
3. Carbon Index method

Heating systems are taken into account as well as fabric. The most flexibility in design is afforded by the Carbon Index method, the target U method is also more flexible than the elemental method.

The elemental method gives maximum allowed values of heat losses for each of the fabric elements, different limits are set for different heating systems, the table below gives the maximum allowed u-values in W/m2K.

| Element of envelope | A type heating | B type heating |
|---|---|---|
| Pitched roof – warm | .2 | .18 |
| Pitched roof – cold | .16 | .16 |
| External Wall | .3 | .27 |
| Floor | .25 | .22 |
| Glazing/doors – metal frame | 2.2 | 2.0 |
| Glazing/doors – wood / PVC | 2 | 1.8 |

More relaxed standards are allowed if higher efficiency heating methods used (gas boiler with SEDBUK > 78% is type A). The total area of the windows + doors + roof-lights (including frames) must be < 25% of the floor area.

The target-U approach is more flexible and can be applied to multi-dwelling buildings. The method is to compare area weighted average fabric U for dwelling or multi-dwelling building to target U calculated by formulae, the formulae to be used depends on the heating system. This method allows trade-offs to be made between elements and allows the solar gains through the windows to be included as a factor. Although flexible there are recommended maximum U values for elements, these are important to reduce condensation risks.

| Element | Max U |
|---|---|
| Roof | .35 |
| Walls / Floors (excludes internal) | .7 |

The carbon index method is the most flexible and allows trade off in building fabric against different supply technologies as long as a specified emission target is met, the CI allows inclusion of district heating schemes, solar hot water systems, heat pumps etc. The carbon index (CI) is defined in SAP 2001 [32] and calculated using the SAP worksheets or approved software (CI is discussed in more detail later). A CI > 8 should be achieved. Although flexible there are recommended maximum U values similar to those for the target U method.

In ‘Limiting Air Infiltration’ (section 6.2.5), the guidance is ‘Provide a continuous barrier around the insulation envelope. One approach is to follow BRE Report 262 ‘Thermal Insulation, avoiding risks’ (2002) which gives guidance on sealing the building fabric during construction. There is no maximum permeability set or requirement to carry out a post construction test.

In ‘Limiting thermal bridging at junctions and openings’ (section 6.2.4), the guidance is given that ‘One approach is to follow BRE Report 262 ‘Thermal Insulation, avoiding risks’ 2002 or demonstrate equivalent performance by calculation. BRE 262 does not require a thermo-graphic survey to be done.

In ‘Heating System Controls’ (section 6.3), the guidance is that ‘Heating and hot water services must be designed installed and capable of being controlled to achieve optimum energy efficiency having regard to the thermal transfer of the insulation envelope’. Some specific control requirements are given for hot water and space heating systems. Controls for space heating include zone controls, timing controls and boiler controls with independent 7 days capability and boiler interlock when no demand. Similarly for Hot Water Controls required are boiler interlock and 7 day timing independent of space heating. EEBPp GPG 302 [33] is referenced which gives detailed guidance. GPG 302 references GIL 59, ‘Central Heating System Specification’ (CHeSS). In ‘Heating System Insulation’ (section 6.4) the guidance is to insulate pipes per BRE 262, BS5422 2001 and insulate vessels per BS5422 2001.

The guidance on ‘Conservatories’ (section 6.M) is that if there is no divide to rest of property then it is not a conservatory but an integral part of the room. Conservatories with heating attached to new dwellings should form part of insulation envelope. If a heated conservatory has floor area > 30m2 then they must meet all regulations and the glazed elements included in the window / door / roof-light area for the elemental method (e.g. 2 W/m2K, < 25% floor area). If a heated conservatory has floor area < 30m2 then window / door / roof-light can have a U value of 3.3 W/m2K. Using target-U or CI methods can allow the conservatory losses to be compensated by super-insulation or alternative heating etc.

The recent Scottish Building Regulations Revisions to the elemental u-values requirements are given in the table below (5$^{th}$ amendment 1999, 6$^{th}$ amendment 2002, proposed 2005, from Scottish Parliament site[30] ). These values are for a high efficiency heating system e.g. gas with SEDBUK > 78%

| **Element** | **2005** | **2002** | **1999** |
|---|---|---|---|
| Pitched roof – warm | .2 | .2 | .35 |
| Pitched roof – cold | .16 | .16 | .25 |
| Flat roof or int insulation | .25 | .25 | .35 |
| External Wall | .3 | .3 | .45 |
| Floor | .25 | .25 | .45 |
| Glaz/door – metal frame | 2.2 | 2.2 | 3.3 |
| Glaz/door – wood/pvc | 2 | 2 | 3.3 |

The ventilation requirements do not change between the 1999, 2002 and 2005 proposed regulations.

It is worth noting that the building regulations give no directions regarding energy and thermal mass, for masonry constructions insulation is shown inside and outside of wall and within cavity.

No guidance is given in the building regulations on electrical appliances or lighting with regard to energy use.

No reference to Eco-homes standards.

### 2.2 UK best practice guidelines

The Energy Efficiency Best Practice in Housing program (EEBPHp) is managed by the Energy Savings Trust (EST) on behalf of the UK Government. The technical content of the best practice documentation is from the Buildings Research Establishment (BRE). The best practice documentation is available through the EST ‘Practical Help’ website [34].

The current best practice in sustainable housing is detailed in the following documents:

1. GIL 72, Energy Efficiency Standards – for new and existing dwellings (2002).[35]
2. GIR 53, Building a sustainable future – homes for an autonomous future (1996). [9]
3. GPG 79, Energy efficiency in new housing – a guide to best practice (2001). [36]
4. GPG 155, Energy efficient refurbishment of existing housing (2001). [37]

In addition to these documents there is a ‘Green Street’ web portal [38] that has been developed to provide sustainability and energy efficiency advice which provides technical and financial data appropriate to the property to be refurbished. The model has been constructed for 8 house types representative of a large proportion of UK housing stock. For properties that are hard to treat and not represented by the 8 house types in ‘Green Street’ there is a further ‘Hard to treat’ web portal [39] which gives access to further options.

There is much more information available which is referenced from these primary documents.

In the following pages each of the primary sources of best practice is briefly reviewed and a summary table presented which captures the key elements of each.

### 2.2.1 GIL 72: Energy Efficiency Standards – For New and Existing dwellings (2002)

This General Information Leaflet is the output of a project to review existing standards, consult with energy efficiency experts and develop new standards for the UK. The key elements of the new standards are summarised in the table below.

| Category / Standard | 'Good'<br>(better than statutory min) | 'Best Practice'<br>(low risk established tech) | 'Advanced'<br>(based on Zero Heating GIR53*) |
|---|---|---|---|
| Cost Increment | 1% | 6% (8% timber) | 11% (20% timber) |
| CI (gas heating) | >8 | >8.6 | >8.6 |
| U (roof) | <.16 | <.13 | <.08 |
| U (walls) | <.3 | <.25 | <.15 |
| U (floors) | <.25 | <.2 | <.1 |
| U (wind/doors) | <3 | <1.8 | <1.5 |
| Air Permeability,<br>CIBSE TM23,<br>m3/h/m2 @ 50pa | <4 (w. HRV)<br><7 (wo. HRV) | <3 | <1 |
| Ventilation<br>BSEN13141/7/8 | PSV, aPSV or HRV | PSV, aPSV or HRV<br>H vent, fan< 2W/l/s,<br>HR > 70% | PSV, aPSV or HRV<br>H vent, fan< 1W/l/s,<br>HR > 85% |
| Daylight factor %<br>(pub,k,bed) | | | 1.5, 2.0, 1.0 |
| EE Lighting | 50%** | 80% | 100% |
| Appliances E rating | A** | A | A |
| Low Water Appl's | | 4, 8, 50, 16** | 4, 6, 50, 16 |
| Central Heating | | CheSS HC4, HR4 | CheSS HC4, HR4 |
| Alt heating BS613 | | | T,t cont - CheSS std |
| Clothes Dry | | In house - ventilated | In house –ventilated |
| Renewables | | | Balance emissions with PV, Wind.<br>(or autonomous**) |
| Survey | | Thermographic** | Thermographic** |

** not basic requirement but recommended to consider.
* high thermal mass construction.

**2.2.2 GIR 53: Building a sustainable future – Homes autonomous community (1996)**

This General Information Report was based on studies carried out by Robert and Brenda Vale for BRECSU with the purpose of defining a standard for autonomous communities. These standards were recommended to be treated as advancing the debate on sustainable housing. Three new standards were proposed 'Zero CO2', 'Zero Heating' and 'Autonomous' and are compared to housing constructed to 1995 building regulations.

| | '95 Regs' | 'Zero CO2' (60% red'n in space heating) | 'Zero Heating' (BREDEM 8 or 12 calc) | 'Autonomous' |
|---|---|---|---|---|
| Costs £/m2 | 450-500 | | | 920 |
| SAP | >60 | | | |
| Heating | GCH | Elec Panel Heat, Green Tariff | Occupancy Operation and Passive Solar | Occupancy Operation and Passive Solar |
| Backup Heating | | Elec Fire | Elec, Green Tf | Elec, Green Tf |
| Heating Cont | Prog Rm/Cyl Stats, TRV | Prog Rm/Panel / Fire Stats and Timers | Prog Rm/Panel / Fire Stats and Timers | Prog Rm/Panel / Fire Stats and Timers |
| HW System | 160 l cyl, 38mm foam insulation | 150 mm foam insulation | 180 l cyl 150 mm insulation cyl and pipes. Elec Imm. | Solar HW Heat Pump |
| Air Leak Rate (ACH@50Pa) | | <3ac/h@50pa | <1ac/h@50pa | <1ac/h@50pa |
| Ventilation | Extract K,B | H cont PSV | HRV eff >60% 8000mm2 trickle vents all windows | HRV eff >60% 8000mm2 trickle vents.. aPSV to cellar |
| U (roof) | <.25 | <.1 300mm ins | <.08 500mm ins | <.08 500mm ins |
| U (floor) | <.45 | <.2 150mm EP Concrete Slab | <.1 300mm EP Concrete Slab | <.1 |
| U (exposed walls) | <.45 | <.2 150mm ins | <.14 250mm ins | <.14 |
| U (unexposed walls) | <.6 | <.2 | <.14 | <.14 |
| U (wind/door) | <3.3 | <2.2 | <1.7 | <1.7 |
| Construction | | | High Thermal Mass | High Thermal Mass |
| Sewage | | | | Compost - Basement |
| Water | | | | Grey recyc |
| EE Lighting | | | 100% | 100% |
| Appliances | | | A | A |
| Space Heating | 7926(gas) | 3172 | 240 (EA est.) | 0 (min T 16.5deg) |
| Hot water | 4548 (gas) | 2319 | 1660 (690 w HP) | 700 (8m2SHWorHP) |
| Pump / Fans | 175 | 0 | 200 | 100 |
| Cooking | 656 (gas) | 330 | 330 | 300 |
| Light/Apps | 3000 | 2700 | 2100 | 1000 |
| E kWh pa. | 16305 | 8521 | 4530 | 2100 |

#### 2.2.3 GPG 79: Energy efficiency in new housing – a guide to best practice (2001)

In response to the Government's target of 4.4 million homes by 2016, this guide is to help house-builders design and build energy efficient homes beyond the current regulations at little or no extra cost. This is targeted at both Housing Associations and Private Developers.

This document gives detailed guidance on design and implementation of a number of key construction elements.

| Element | Guidance | Comments |
|---|---|---|
| Ratings | SAP of >100 if targets met, CI ~8. | |
| Passive Solar | Living area to south<br>Avoid overshadowing<br>Space between dwellings<br>Maximise south glazing without inc total glazing area.<br>Conservatories not recommended. | Enclosed draught lobbies<br>Garages to shelter N elev<br>Avoid large mid stairwells in flats or stairwells direct from living areas.<br>Heating responsive (trv) |
| Insulation and Construction | Avoid thermal bridging<br>Timber frame to have vapour control layer on warm side and breather membrane on outer. | Details given of bridge avoidance.<br>Avoid air movement behind inner leaf. |
| External Wall U (W/m2K) | 0.2 target<br>0.3 minimum | Construction details given timber frame and masonry, high and low mass. |
| Floor U (W/m2K) | 0.2 | Details given for various constructions high and low mass. |
| Roof U (W/m2K) | 0.16 | Construction details given |
| Windows U (W/m2K) | <2 (whole window)<br><1 (door) | Construction details given |
| Ventilation / Condensation | 0.5 – 1 ac/h ave natural.<br>5-7m3/hr/m2@50pa if local extract + trickle<br>4m3/hr/m2@50pa if HRV | Build tight, ventilate right<br>Design details given …<br>Humidistat controls @ 70%rh. |
| Heating | CHeSS HR2 and HC2combi standards for gas<br>Condensing boilers<br>CHP, SHW consider.. | SEDBUK eff > 82%<br>High perf cylinder (non combi)<br>Prog tmr, room stats/trv…<br>Implementation guidance.. |
| Lighting / Appliances | EE CFLs, A rated Apps | Daylighting max<br>PIRs as appropriate |

### 2.2.4 GPG 155: Energy efficient refurbishment of existing housing (2001)

The aim of this document is to guide landlords, private developers and others to refurbish and repair their housing in an energy efficient way.

The document gives a matrix which identifies which energy efficiency options can be integrated with a variety of standard improvements or upgrades to the property. BREDEM and SAP are recommended tools.

The following illustration is given for a typical mid terrace house with gas central heating:

| Improvement added | SAP Score | Annual Heat and HW (£) |
|---|---|---|
| As is | 43 | 500 |
| Windows double glazed and draught-stripped | 46 | 470 |
| Fully insulated and double glazed | 85 | 210 |
| Fully insulated, double glazed, condensing boiler | 102 | 160 |

The recommended measures are summarised in the following table. The document gives detailed information on correct implementation (avoidance of thermal bridging etc).

| Situation | Typ. existing U (W/m2K) | Measure | Resultant U (W/m2K) |
|---|---|---|---|
| Cavity walls | 1.5 | Cavity fill | .52 |
| Solid 225mm brick | 2.1 | Internal lining | <.45 |
| | | External lining | <.35 |
| Pitched Roof | 1.9 | 250mm insulation | .16 |
| Floor | 0.45-0.7 | Insulate | <.2-.25 |
| Glazing | 4.7 | Replace | <1.8 – 2 |
| Doors | 3 | Replace | 1 |
| Draught-proofing | Reduce non controlled ventilation | Draught-strip w/d/l. Seal Joints w/d/dw/floors. Seal chimneys and service ducts. Add draught lobbys (consider open access balcony). | Don't draught-strip kitchen and bathroom windows. Ensure vent to appliances. |
| Ventilation / Avoid condensation | 0.5 – 1 ac/h natural vent rate required. | Trickle vent all windows + extract or passive vent in Kitchen and Bathroom OR Whole house HRV | Extract fans with humidistat control <70% rh. > 60l/s kitchen, >15l/s bathroom. |
| Heating / Hot Water System<br><br>Note: also consider group/district or community system. | Typ old heavyweight boiler 50-60% efficient | CHeSS HR4 or HC4 standard system. Condensing boiler, high perf cyl and pipes, prog timers stats, trv's etc. | Condensing boiler 85-92% efficient |
| Lighting / Appliances | | Low Energy lighting, A rated appliances | |

### 2.2.5 The Green Street Web Tool / Portal [38]

This is a Government sponsored web tool / portal to sustainability and energy efficiency advice for refurbishing existing housing stock. The model is BREDEM based and has been constructed for 8 house types representative of a large proportion of UK housing stock.

## Welcome to Green Street

There are four million homes maintained and managed by housing associations and local authorities. If these valuable assets are to meet the changing needs of residents and local communities now and in the future, their environmental performance needs to be carefully considered and improved.

The Government-appointed Sustainable Task Group in their latest report recommend action be taken to reduce the impact of exisiting buildings, and point to Green Street as one of the ways to do this.

A wealth of information is available on this issue from many sources. For the first time Green Street has begun to bring this information together in one place to make it easier for you to make the improvements.

Green Street will help you improve the environmental performance of your homes.

Green Street contains detailed information and advice on why and how to take action to improve your homes in the following areas:

- energy efficiency
- water efficiency
- material use
- waste reduction
- health and wellbeing
- residents' lifestyle, and
- the overall environmental improvement of your stock.

When you visit Green Street you will find a range of homes to reflect the general stock. There are eight different house and flat types on show. You can find information by housetype, or more generally on any of the above issues.

### 2.2.6 The Hard to Treat Web Tool / Portal

For properties that are hard to treat and not represented by the 8 house types in 'Green Street' there is a further 'Hard to treat' web portal [39] which gives access to further options.

| | House typ | Period Terrace | Flats: Period conversi | Tenement flats | Semi detached | System built flats | Modern terrace | High rise | Modern medium rise |
|---|---|---|---|---|---|---|---|---|---|
| Heating Measures | Off peak Electric storage | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| | Bulk LPG | ✓ | | | ✓ | | ✓ | | |
| | Air source heat pump | ✓ | ✓ | | ✓ | | ✓ | | |
| | Solid fuel central heating | ✓ | | | ✓ | | ✓ | | |
| | Wood pellet central heating | ✓ | | | ✓ | | ✓ | | |
| | Ground source heat pump | ✓ | | | ✓ | | ✓ | | |
| | Oil central heating | ✓ | | | ✓ | | ✓ | | |
| | Gas central heating | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Micro CHP (Gas) | | | | ✓ | | | | |
| | CHP | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Fabric Measures | External insulation | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ |
| | Internal insulation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Insulating render | | ✓ | ✓ | ✓ | ✓ | | | |
| | Loft insulation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| | Flat roof insulation | ✓ | | ✓ | | | | | ✓ |
| | Cavity wall insulation | | | | | ✓ | ✓ | ✓ | ✓ |
| | Flexible insulated linings | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Double glazing | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Secondary glazing | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Solar water heating | ✓ | ✓ | | ✓ | | ✓ | | |
| | Hot water tank insulation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Floor insulation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Draught-stripping | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ventilation | Local extract fans | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Heat recovery room ventilators | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Passive stack ventilation | ✓ | ✓ | | ✓ | | ✓ | | |
| | Whole house mechanical ventilation | | | | ✓ | | ✓ | | |
| | Mechanical supply (+ve pressure) ventilation | ✓ | | | ✓ | | ✓ | | |

For each of the options selected the tool gives a report on the financial and carbon impact of the measure, an example is shown below.

EXTERNAL WALLS: INTERNALLY APPLIED INSULATION
Description
Insulation layer between steel channels or timber studs on the inside of walls, most commonly covered by foil-backed plasterboard (or plasterboard with separate vapour control layer) fixed to the channels or studs. Alternatively composite boards of insulation and plasterboard are adhered and/or mechanically fixed to substrate.
Unit cost of installation
£1200 (to U value 0.35); £1000 (to U value 0.45). Cost will depend on type of system used. Composite boards vary in price - for a given U-value polystyrene-backed boards are cheapest and thickest while phenolic-backed boards are the most expensive and thinnest.
Bulk cost of installation
Data not available.
Indicative cost and carbon saving

| | £/yr saving | | kgC/yr saving | |
|---|---|---|---|---|
| | from | to | from | to |
| Internal insulation to U-value 0.35 $W/m^2K$ | 115 | 490 | 460 | 1110 |
| Internal insulation to U-value 0.45 $W/m^2K$ | 110 | 465 | 440 | 1060 |

Maintenance

### 2.3 UK Models and assessment criteria (BREDEM, SAP, CI, ECOhomes)

#### 2.3.1 BREDEM

The Buildings research establishment (BRE) developed the BRE Domestic Energy Model (BREDEM) in the early 1980's [40]. The BREDEM model calculates the space heating requirements of a dwelling based on an energy balance allowing for heat transmission through building elements, ventilation, internal temperatures and heating patterns, external climate, internal gains, solar gains, appliance efficiency and the interactions between these factors. The BREDEM model uses values for occupancy, water heating, cooking, lighting and electrical appliances based on estimates based largely on statistical analysis of measured data. There are 3 current versions of BREDEM, BREDEM-12 and BREDEM-8 are both 2 zone models (living zone, rest of house) and give annual and monthly data respectively, BREDEM-9 is simplified single zone version of BREDEM-12 which is used as basis of SAP calculations (spreadsheet friendly). The BREDEM model is documented in detail in BRE literature [40,41].

The basic BREDEM methodology is as follows:

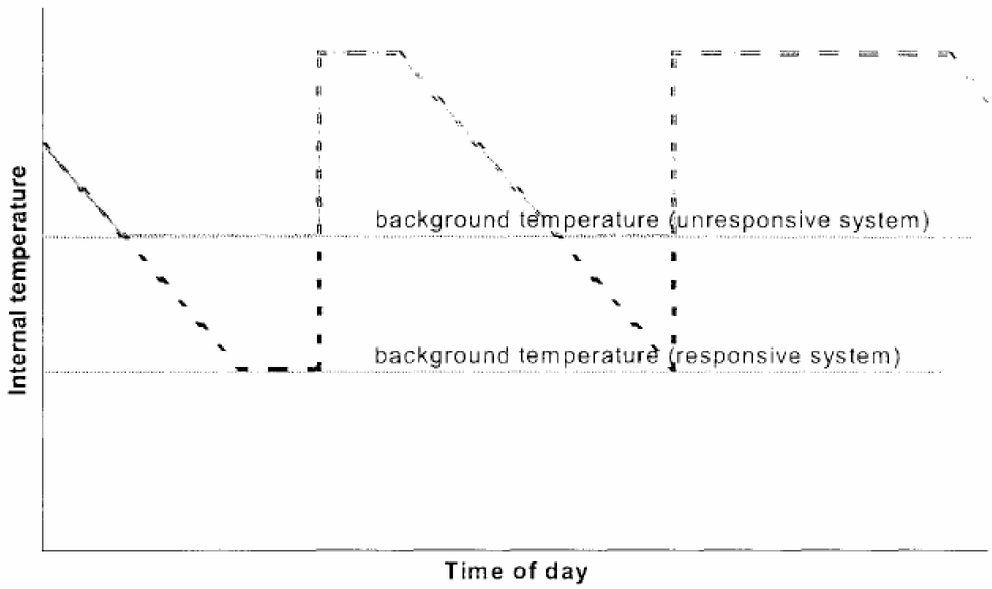
1. Establish heat losses through fabric and ventilation.
    - Input elemental u values and areas.
2. Establish occupancy based on floor area.
    - Occupancy based on empirical equation based on survey data.
2. Establish gains form occupants, hot water, appliances and solar.
    - Based on tables or empirical equations derived from survey data.
    - Includes usefulness factor.
3. Establish the mean internal temp for given demand temp, heating schedule and heating system and also the base temp.
    - Mean temp based on equations and tables derived from survey data.
    - Base temp from the mean temp minus the contribution due to gains.
4. Establish Space Heat Energy Consumption from climate degree day data.
    - Table of degree days for given base temp and local climate.
5. Establish Primary Energy for Heating.
    - Space Heat Energy divided by the delivery system efficiency.
6. Establish Primary Energy for Hot Water from occupancy and efficiency of system.
    - Efficiency calculated based on system details.
7. Establish Cooking Energy.
    - Values for gas or electric based on survey data.
8. Lighting and Electrical Appliances.
    - Equations based on survey data dependent on area and occupancy.
    - Low energy lighting factor.

There are some allowed variations for low occupancy or high occupancy with adjustments of +20% to -40% suggested.

The BREDEM model does not explicitly take account of thermal mass in the building. It is recognised that thermal mass can have an effect [41] but it is stated that analytical studies have shown effect of thermal mass to be small in well insulated houses with intermittent heating and references Uglo's 1980 paper. It is also stated that in poorer insulated houses the effect is greater but that as all poorly insulated houses in the UK are of high thermal mass then it can be assumed that the mean temperatures for poor insulation cases are for high mass and for the good insulation case apply to both light and heavy thermal mass constructions.

The responsiveness of the heating system is however modelled and its effect on the mean temperature as shown in the diagram below. It would seem possible and reasonable that a similar factor could be added to account for different thermal mass in construction.

**Figure 6.1 The effect of heating system responsiveness on internal temperature**



### 2.3.2 The Governments Standard Assessment Procedure (SAP) and Carbon Index (CI)

SAP is the Governments Standard Assessment Procedure for Energy Rating of Dwellings. The latest revision is SAP 2001 [32] which was published by the Buildings Research Establishment (BRE).

The SAP rating is based on calculated annual energy for Space Heating and Water Heating. The procedure for the calculation is based on the BRE Domestic Energy Model (BREDEM).

The calculation assumes a standard occupancy pattern derived from the dwelling floor area and a standard heating pattern.

Output from SAP 2001 is an SAP rating in the range of 1 to 120 plus a Carbon Index (CI) score in the range of 0 to 10. Ratings are provided by accredited assessors using BRE approved software.

The SAP and CI assessment procedure follows steps 1 – 6 of the BREDEM methodology outlined in the previous chapter to calculate the primary energy for space and hot water heating. Next the primary fuel cost is determined and from this the SAP score. The Carbon Index (CI) is calculated from the CO2 emissions associated with the primary energy production.

The SAP score relates to the annual cost of space and water heating per square metre of floor area. There is an energy cost deflator which it is stated will vary so that SAP scores are independent of general increases due to inflation but the SAP score will reflect relative changes in fuel prices.

The CI score relates to the CO2 emissions per year from the primary energy consumed for space and hot water heating. There are carbon emission factors given for each primary fuel type.

It is important to note that the CI and SAP ratings only relate to Space and Water Heating and that Energy for Lighting, Cooking and Appliances is not considered other than as a source of gains.

The SAP 2001 document provides the worksheet, tables and equations that are used in the assessment procedure. As part of this project an Excel worksheet has been constructed to allow the influence of different parameters to be assessed and allow SAP and CI scores derived for a number of different scenarios (covered in comparisons and discussion section). A commented version of the spreadsheet is shown below.

The Governments SAP 2001 document gives guidelines on how to treat elements such as conservatories, porches and garages. These spaces are treated as sheltering elements which reduce the effective u-value of the wall being sheltered if they are unheated and there is a separating door between the space and the heated dwelling. If they are heated then they should be included within the dwelling as an additional room.

The minimum ventilation rate allowed is 0.5 ac/h as it is assumed that people will ventilate to at least this rate.

The proposed 2005 building regulations expect a dwelling to have a Carbon Index of > 8. This typically relates to an SAP score of > 90 however this relationship is not fixed as although both are calculated from primary energy use for space and water heating the fuel costs which drive the SAP score and the CO2 emissions which drive the CI index may change independently.

SAP 2001 CALCULATION SHEET

| | | | |
|---|---|---|---|
| Ground floor area | m2 | 50 | |
| Number of floors | num | 2 | |
| Room height | m2 | 2.4 | |
| Dwelling volume | m3 | 240 | |
| Number of chimneys | num | 0 | 40m3/hr/chimney |
| Number of flues | num | 4 | 20m3/hr/flue |
| Number fans or passive vents | num | 0 | 10m3/hr/fan or vent |
| Infiltration ch/f/f | ac/h | 0.333333 | |
| Number stories | num | 3 | |
| Infiltration stories | ac/h | 0.2 | |
| Structural infiltration | ac/h | 0.35 | 0.25 for steel / timber, 0.35 for masonry |
| Suspended wooden floor | ac/h | 0.2 | 0.2 unsealed, 0.1 sealed, or 0 |
| Draught lobby | ac/h | 0.05 | 0.05 if no draught lobby, else 0 |
| Percent windows draught stripped | % | 30 | |
| Window infiltration | ac/h | 0.19 | |
| Infiltration rate | ac/h | 1.323333 | |
| or if press test done then q50/20+[10] | | | |
| Sheltered sides | num | 2 | |
| Shelter factor | num | 0.85 | |
| if MVHR eff ach rate | ac/h | 1.294833 | if no MVHR add 0.33 to this! |
| if natural ventilation ach rate | ac/h | 1.124833 | |
| if nat vent rate < 1 then nat vent modified | ac/h | 1.132625 | occupants open windows if ac/h <1 |
| final vent rate MVHR or Nat | ac/h | 1.124833 | assumes natural vent |

| Element | Area(m2) | U(W/m2K) | AxU(W/K) | |
|---|---|---|---|---|
| Doors | 3 | 2 | 6 | |
| Windows | 20 | 2 | 36 | factor of 0.9 assumes use of curtains |
| Ground floor | 50 | 0.25 | 12.5 | upper flat |
| Walls | 76 | 0.3 | 22.8 | |
| Roof | 100 | 0.25 | 25 | note: if conservatories garages etc then more detail |
| Other | 0 | 0 | 0 | needed to capture the buffer effects etc. |
| Total | 249 | | 102.3 | Fabric loss |

| | | | |
|---|---|---|---|
| Ventilation heat loss | W/K | 89.0868 | Vent loss |
| Heat loss co-eff (Vent+Fabric) | W/K | 191.3868 | |
| Heat Loss Parameter HLP | W/m2K | 1.913868 | |
| Occupancy N | num | 3.12 | calculated, floor area < 450m2 (8 if TFA>450m2) |
| Hot water energy req't | GJ/yr | 7.567707 | calculated, also tables available |
| Distribution loss | GJ/yr | 1.335478 | calculated, also tables available |
| Water storage volume | Litres | 40 | |
| Volume factor VF | num | 1.44 | from table, also calc avail |
| Water storage loss factor | GJ/yr/litre | 0.0026 | from table, loose jacket tins >= 25mm |
| Energy lost from water storage | GJ/yr | 0.14976 | |
| Area of solar panel | m2 | 0.001 | solartwin |
| solar energy available | GJ/yr | 0.0013 | assumes 1.3GJ/yr per m2? = 360kWh/m2 |
| load ratio | num | 5821.313 | |
| solar input | GJ/yr | 0.0013 | |
| Primary water circuit loss | GJ/yr | 2.2 | boiler, uninsulated primary, boiler stat, table 3 |
| Output from water heater | GJ/yr | 11.25165 | |
| Water heater efficiency | % | 78 | |
| Energy required for water heating | GJ/yr | 14.42519 | |
| Heat Gains from water heating | GJ/yr | 4.840117 | |
| Internal gains-lights,apps,cook,meta | W | 585.56 | calc based on TFA and N, for TFA < 282m2, also 10W heating syst pump |
| Water heating gains in W | W | 153.4801 | ignores low energy lighting! |
| Total internal gains | W | 739.0401 | |

| Solar Gains - element orientation | F-access | Area(m2) | Flux | Gains(W) |
|---|---|---|---|---|
| North | 1 | 10 | 13 | 130 |
| East | 1 | 0 | 22 | 0 |
| South | 1 | 10 | 32 | 320 |
| West | 1 | 0 | 22 | 0 |
| Rooflights | 1.3 | 0 | 13 | 0 |
| Total solar gains | | | | 450 |

| | | | |
|---|---|---|---|
| Total gains | W | 1189.04 | |
| Gains to loss ratio GLR | K | 6.212759 | |
| Utilisation Factor | num | 0.94 | table 7, more gains less utilisable. |
| Useful gains | W | 1117.698 | |
| Mean internal temperature of living room | C | 19 | table 8, depends on HLP |
| Temp adjust for controls | C | -0.6 | table 4e |
| Adjustment for gains | C | 0.367999 | |
| Adjusted living room temp | C | 19.232 | |
| Temp diff between zones | C | 0.6 | table 9, depends on HLP, controls |
| Living area fraction | num | 0.2 | living room area / total floor area |
| Rest of dwelling fraction | num | 0.8 | |
| Mean internal temperature | C | 18.752 | |
| Temp rise from gains | C | 5.839994 | |
| Base temp | C | 12.91201 | |
| Degree days | DD | 1440 | from table 10 and base temp |
| Space heating energy requirement | GJ/yr | 23.81158 | |
| Fraction of heat from secondary system | num | 0.15 | table 11 |
| Efficiency of heating system | % | 78 | |
| Efficiency of secondary system | % | 78 | |
| Space heating fuel (main) | GJ/yr | 25.94852 | |
| Space heating fuel (secondary) | GJ/yr | 4.57915 | |
| Electricity for heating pumps etc | GJ/yr | 0.47 | |
| Fuel costs - space heating main | £/yr | 97.04745 | table 12 for fuel prices |
| Fuel costs - space heating secondary | £/yr | 17.12602 | |
| Fuel cost - water heating | £/yr | 53.9502 | |
| Pump and fan costs | £/yr | 9.776 | |
| Standing charges | £/yr | 28 | |
| Total heating cost | £/yr | 205.8997 | |
| Energy cost inflator | num | 1.05 | table 12 for fuel prices |
| Energy cost factor ECF | num | 1.284101 | |
| SAP rating | num | 86.14008 | calc or table 14 |

| Carbon Index - element | Energy(GJ/yr) | Emission factor | Annual Emissions (kg/yr) |
|---|---|---|---|
| Water heating | 14.42519 | 54 | 778.9601 |
| Space heating main | 25.94852 | 54 | 1401.22 |
| Space heating secondary | 4.57915 | 54 | 247.2741 |
| Electricity for heating pumps etc | 0.47 | 115 | 54.05 |
| Total CO2 | | | 2481.504 |
| Carbon factor CF | num | 17.11382 | |
| Carbon Index | num | 6.599877 | calc or table 16 |

### 2.3.3 EcoHomes

EcoHomes was developed by the Buildings Research Establishment (BRE) in the 1990's and the latest version released in 2003 as a standard environmental assessment method targeted at new and renovated homes including houses and apartments. A good summary of the EcoHomes standard and its application is given in the Energy Savings Trust Practical help for Local Authorities briefing note ' EcoHomes: An environmental assessment method for homes'. The EcoHomes website gives a rating prediction checklist and guidance and worksheets [3].

The EcoHomes scores are allocated in 7 categories:

**1. Energy** (sections Ene1 – Ene5, 40 points allocated = 21%)
a. Reduction in $CO_2$ emissions.
b. Improvement to fabric of building.
c. Provision of secure drying space.
d. Provision for eco-labeled white goods.
e. Provision of low energy external lighting systems.

**2. Transport** (sections Tra1 – Tra4, 16 points allocated = 8%)
a. Access to public transport.
b. Provision of a cycle store.
c. Proximity to local amenities.
d. Provision for home office.

**3. Pollution** (sections Pol1 – Pol3, 28 points allocated = 15%)
a. Reducing ozone depleting substances.
b. Specifying low $NO_x$ emitting boilers.

**4. Materials** (sections Mat1 – Mat4, 31 points allocated = 16%)
a. Sustainable managed timber.
b. Storage of recyclable waste.
c. Obtaining an A-rating from BRE Green Guide to Housing Specification [ ].

**5. Water** (sections Wat1 – Wat2, 18 points allocated = 9%)

**6. Land use and ecology** (sections Eco1 – Eco5, 12 points allocated = 14%)
a. Ecological value of site.
b. Change of ecological value.
c. Building footprint.

**7. Health and wellbeing** (sections Hea1 – Hea3, 32 points allocated = 17%)
a. Provision of adequate day-lighting.
b. Improved soundproofing.
c. Provision of open space.

Awards are allocated based on percentage of points achieved:

| | |
|---|---|
| Pass | > 36% |
| Good | > 48% |
| Very Good | > 60% |
| Excellent | > 70% |

The WWF has reported that after a period of consultation there was "a general consensus that the BRE EcoHomes standard was a good starting point to define what is a 'sustainable home'." The WWF also suggests that the government should commit to all new developments being to a minimum of BRE EcoHomes 'Very Good' and that levers are built into planning decisions to encourage 'Excellent' developments [42].

The Housing Corporation who fund most of the UK social housing have an EcoHomes ‘Pass’ as a minimum requirement and ‘Good’ as a recommended target while there is a growing trend for planning authorities to set EcoHomes targets as part of Supplementary Planning Guidance [42].

Michael Priaulx, an EcoHomes assessor in his article in Building for a Future [43] has examined “how sustainable the EcoHomes Standard really is?” and in response to the question “Can EcoHome dwellings really be called ‘sustainable’?” concludes “There is no doubt that meeting an Excellent, Very Good or even Good rating will bring about a significant improvement in environmental performance compared to a typical dwelling built to building regulations by a volume house-builder”. Priaulx reviews each of the categories and discusses anomalies and areas of debate over the ratings and weightings.

The Energy section is made up of Ene1 through Ene5:

Ene1 Carbon Dioxide (20 points):
This section awards points based on the $CO_2$ emissions to atmosphere due to operation of the home and its services. The space and water heating primary fuel consumption is calculated from the SAP 2001 methodology, the electricity for lights and appliances is calculated using the EcoHomes formula Ela=LeffxTFA where Leff is a factor dependent on the extent of low energy lighting. The $CO_2$ emissions are then calculated using EcoHomes emission factors (different to SAP2001). Allowances are then made for renewables, CHP and air conditioning to give an output in Kg/m2/yr which is compared to a look up table.

Ene2: Building Envelope Performance (10 points):
Points are allocated dependent on the % improvement over building regulation maximums.

Ene3: Drying Space (2 points):
Points allocated if space provided to required standard.

Ene4: Eco Labeled White Goods (4 points):
All fridges, freezers to be A rated, washing machines and dishwashers to be A rated, washer dryers ands dryers to be C rated or higher.

Ene5: External Lighting (4 points):
Points for provision of low energy external lighting.

It should be noted that no credits are allocated directly based on thermal mass and although the Green Guide for Housing Specification tends to give best scores for lightweight constructions the soundproofing credits may be easier to achieve with heavier mass constructions.

Due to the broad spectrum of categories that are rated for sustainability it is possible to perform poorly against one section and still achieve an ‘Excellent’ rating e.g. with zero points for Energy there are still 79% of points available v the Excellent requirement of 70%.

An excel sheet has been constructed to carry out the Energy Section EcoHomes assessment which uses the previously described SAP 2001 worksheet, a commented image from this sheet is given below. This is used in the ‘Comparisons and Discussion’ section.

ECOhomes criteria

| ENE 1 : Energy Carbon Dioxide (10) | kg/GJ | kgCO2/yr | |
|---|---|---|---|
| Power use -> CO2 Emissions | GJ/yr | Em-factor | Ann Emm |
| Hot water heating | 14.42519 | 53 | 764.5349 |
| Space heating | 30.52767 | 53 | 1617.966 |
| Heating Pumps/fans | 0.47 | 144 | 67.68 |

| | | | |
|---|---|---|---|
| Heat from renewables (space) | GJ/yr | 0 | |
| Heat from renewables (hw) | GJ/yr | 0 | |
| Elec from renewables? | GJ/yr | 0 | |
| Low energy light factor | num | 0.087 | 0.0870 if no low energy light fittings |
| Lights/appliances | GJ/yr | 8.7 | 0.0814 if partial and 0.0758 if fully low e. |
| Em-factor | kg/GJ | 144 | assumes that 16% of lights and appliances is |
| Ann Emm | kgCO2/yr | 1252.8 | |
| Total Emissions | kgCO2/yr | 3702.981 | |
| Total Emmisions/m2 | kg/m2/yr | 37.02981 | |
| Energy Credits ENE1 | | 7 | From 10 Available |

different factors from SAP2001

| | ECOhomes | SAP |
|---|---|---|
| Fuel Type | CO2 kg/GJ | CO2 kg/GJ |
| Elec | 144 | 115 |
| Gas | 53 | 54 |

| Credits | CO2kg/m2/yr |
|---|---|
| 1 | <60 |
| 2 | <50 |
| 3 | <45 |
| 4 | <35 |
| 5 | <30 |
| 6 | <27 |
| 7 | <25 |
| 8 | <20 |
| 9 | <10 |
| 10 | <0 |

| ENE 2 :Building Fabric (5) | |
|---|---|
| Improve insulation standards | improvement to building regs |
| Buildings under 2002 regs | |
| Utarget | 0.419478 |
| Uaverage | 0.410843 |
| Percentage improvement | 2.058401 |
| Buildings under 1995 regs | |
| Utarget | |
| Uaverage | |
| Percentage improvement | |
| Ene 2 Credits (5) | |

| | Improvement in ave u v Regs | |
|---|---|---|
| Credits | 2002 | 1995/refurb |
| 1 | >3% | >10% |
| 2 | >6% | >15% |
| 3 | >9% | >20% |
| 4 | >12% | >25% |
| 5 | >15% | >30% |

ENE 3 :Drying Space (1)
provision

ENE 4 :Ecolabeled white goods (2)

ENE 5 :External lighting (2)
low energy

| Rating | Score |
|---|---|
| Pass | 36 |
| Good | 48 |
| Very Good | 60 |
| Excellent | 70 |

### 2.4 European Building Regulations

The table below gives a brief comparison of u-values and some air-tightness for UK proposed 2005 Building Regulations and Best Practice Standards to some European Countries (Denmark (DK), Sweden (SV), Norway (N)) for which data was available from the John Gilbert website [24].

It can be seen that that the walls, floor and glazing u-values for the Scandinavian countries are tighter than the proposed 2005 regulations and generally lie between our 'Best Practice' and 'Advanced' standards.

| Element | Adv | BP | Good | 2002 | DK | SV | N | PH |
|---|---|---|---|---|---|---|---|---|
| Pitch roof warm | .08 | .13 | .16 | .2 | .2 | | | |
| Pitch roof cold | .08 | .13 | .16 | .16 | .15 | .2 | .15 | .1 |
| Flat roof | .08 | .13 | .16 | .25 | | | | |
| External Wall | .15 | .25 | .3 | .3 | .2 | .18 | .22 | .1 |
| Floor | .1 | .2 | .25 | .25 | .2 | .2 | .22 | .1 |
| Glaz / dr | 1.5 | 1.8 | 3 | 2 | 1.8 | 1.5 | 1.6 | .8 |
| Airtightness ac/h 50Pa | 1 | 3 | 7 | | | | | .6 |
| Max % glazing | | | | 25 | 22 | | | |

### 2.5 EU Passive house, CEPHEUS

This standard was the subject of the THERMIE project BU/0127/97 title 'Cost Efficient Passive Houses as European Standards' (CEPHEUS) [28]. More than 1000 houses have been built to the passive house standard in Germany and Austria. The CEPHEUS project has monitored more than 250 of the passive houses across Switzerland, Germany, Austria, France and Sweden. A passive house is defined as follows [28]:

'The term "Passive House" refers to a construction standard. The standard can be met using a variety of technologies, designs and materials. It is a refinement of the low-energy house (LEH) standard. "Passive Houses" are buildings which assure a comfortable indoor climate in summer and in winter without needing a conventional heating system. To permit this, it is essential that the building's annual demand for space heating does not exceed 15 kWh/m² pa. The minimal heat requirement can be supplied by heating the supply air in the ventilation system – a system which is necessary in any case. The standard has been named "Passive House" because the passive heat inputs – delivered externally by solar irradiation through the windows and provided internally by the heat emissions of appliances and occupants – essentially suffice to keep the building at comfortable indoor temperatures throughout the heating period. The target of the CEPHEUS project is to keep the total final energy demand for space heating, domestic hot water and household appliances below 42 kWh/m² pa. This is lower by at least a factor of 4 than the specific consumption levels of new buildings designed to the standards presently applicable across Europe.'

| Passive house component | Detail specification | Further details |
|---|---|---|
| Performance | Space heating < 15kWh/m2/a, total energy input < 42kWh/m2/a | Max 10W/m2 heat load. |
| passive solar gain | Optimise south glazing to give 40% space heating. | |
| Super-glazing | U <= 0.75 W/(m2K) | low e triple glazing, Tx > 50% |
| Super-frames | U <= 0.8 w/(m2K) | |
| Super-insulated building shell | U =~ 0.1 W/(m2K) desired < 0.15 max. | Simple compact shell form |
| Building element junctions | Thermal transmittance < 0.01 W/(mK) | |
| Airtightness | < 0.6 ac/h @ 50Pa | Building pressure test. Airtight penetrations. |
| Hygienic ventilation | 30 m3/h/person | Extract from damp rooms. Controls l/m/h, additional in wet rooms. |
| Heat recovery | Eff > 80% | Counter-flow air to air exchanger |
| Latent heat recovery | Max heat load 10W/m2 | Compact heat pump unit in exhaust air |
| Air Heating on extreme days | fresh air temp >= 8 deg | Subsoil heat exchanger for fresh air pre-heating (option) |
| Appliances | High efficiency. Hot water to appliances. LEL. DC Ventilation fans < 0.4 Wh/m3 | Minimise electricity demanded. |
| Meet demand by renewables | Solar hot water or heat pump | Offset demand by renewable |

A primary aim of the CEPHEUS project has been to demonstrate carbon neutrality. The Hannover-Kronsberg passive housing development of 32 dwellings which has solar collectors, supplementary heat supply from district heating from combined heat and power (CHP) achieves climate neutrality through a share in a wind energy facility integrated in the house purchase price.

One potential negative of the super-insulation is up to 7.5% reduction in floor area in a typical Swedish detached house where the same external footprint is used [28].

### 2.6 EU Directive on the Energy Performance of Buildings

The EU Directive on the Energy Performance of Buildings [44] became law on 4th Jan 2003, it must be translated into national law by 4 Jan 2006 although there could be delays of up to 3 years for articles 7,8,9 if national governments find there are not sufficient experts available.

A major change is to be the introduction of an Energy Performance Certificate which must show performance against a benchmark and include recommendations for cost-effective improvements. This Energy Performance Certificate is to be made available to the owner, or prospective owner and tenant of a building and must be issued within the last ten years.

It is expected that for homes the performance will be based on SAP / BREDEM.

### 2.7 Building Energy Simulation, ESP-r, IEA BESTEST

In the BREDEM section it was highlighted that the BREDEM model does not consider Thermal Mass in its calculation of energy use. BREDEM is primarily an empirical model based on curve fitting survey data.

In order to analyse more rigorously and on a real-time basis with real climate data it is necessary to use a building simulation tool such as ESP-r, Energy+ or TRNSYS.

ESP-r is a building energy analysis tool developed initially by Joe Clarke of Strathclyde University's Energy Systems Research Unit (ESRU) in the 1980's and developed over 25 years. The basic theory behind the simulator is described in Clarke's book [45] and multiple validation studies are described in the ESRU technical report 'ESP-r: Summary of Validation Studies' [46]. ESP-r has been evaluated as part of the IEA Building energy analysis tool evaluation (BESTEST) [47] and was recently selected after a global survey as the tool of choice to be the basis of the next generation Canadian building energy simulation tool ESP-r/HOT3000 [48].

For the purposes of this thesis ESP-r will be used as the simulation tool.

# Chapter 3:

# Comparative analysis of sustainable housing standards and best practice examples

In this chapter the different standards (including guidelines) and best practice examples (benchmarks) are compared and observations made. A detailed comparison is made for each of the key elements relating to sustainable energy use. Then standard metrics are generated and a quantitative comparison is made.

### 3.1 Comparison of Standards and Benchmarks against key elements of sustainability

In the table below the following standards, regulations, guidelines and examples are compared:

a) The UK Proposed 2005 regulations [30]
b) The UK Best Practice Standard (GPG79, GIL72) [36,35]
c) The UK Advanced Standard (GIL72, GIR53) [ 9]
d) The UK EcoHomes Standard [3]
e) The Passive-House Standard [28]
f) The Vales Autonomous House [8]
g) The Hockerton Housing Project [10,11]
h) The BedZED Zero Energy Development [12,13,14,15]

The elements of sustainability relating to energy which are examined are:

1) Building Envelope and Construction
2) Ventilation
3) Passive Solar and Thermal Mass
4) Space and Water Heating Systems and Controls
5) Lighting, Appliances and Cooking
6) Water Use, clothes dry
7) Supply options
8) Metrics

The comparison table is discussed in the following sections.

| Item | 2005 UK Building Regulations | UK Best Practice GPG79, GIL72 | UK Advanced GIL72 (based on GIR53 zero heat) | UK EcoHomes Standard | EU Passive-House | Vales Autonomous House | Hockerton Housing Project | BedZED Development | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Wall U | Max < .3 | Max < .3 | Max < .15 | Max < .298 | Max < .15 | .14 | .11 | .11 | UK regs ~ 0.3. Advanced <0.15. |
| Roof U | Cold .16 Warm .20 | Max < .16 | Max < .08 | Cold < .14 Warm < .17 | Max < .15 | .07 | .11 | .1 | |
| Floor U | Max < .25 | Max < .2 | Max < .1 | Max < .21 | Max < .15 | .2 | .11 | .1 | |
| Glazing and door U (inc frames), transmission | Max < 2 | Max < 2 (whole window) Max < 1 (door) | Max < 1.5 | Max < .17 | Max < 0.8 Tx > 50% | 1.15 (argon triple glazed) | (argon triple glazed low e inside double glazed low e conservatory) | 1.2 (argon triple glazed low e inside double glazed low e conservatory) | Passive-house 0.8 u-value windows are available in volume. Conservatory may allow larger glz area. |
| Thermal bridge | Construction detailed guidance - BR262. | Avoidance of thermal bridging – detailed guidance. | No guidance given (except 'consider thermo-graphic survey'). | Overall U 15% improvement on '02 regs. No account taken of thermal bridges. | < 0.01 W/mK linear thermal transmittance | Designed to be bridge free. | Outside insulation avoids bridging. | Outside insulation avoids bridging. | No breathing walls. No values for bridging in UK regs. No thermo-graphic survey required. |
| Airtightness / Breathability | Construction guidance – BR262 – no test, no tgt. no breathing walls. | <4m3/hr/m2 @50 if MVHR. <7m3/hr/m2 if trickle + wet extract. | <1m3/h/m2@50 (GIR53 z heat, < 1ac/h50) | | <0.6ac/h50, Pressure test | 1.5 ac/h50 | Good by construction. | Good by construction. < 2.5 ac/h50 | No air-tightness max spec or pressure test required in regulations. |

| Item | 2005 UK Building Regulations | UK Best Practice GPG79, GIL72 | UK Advanced GIL72 (based on GIR53 zero heat) | UK EcoHomes Standard | EU Passive-House | Vales Autonomous House | Hockerton Housing Project | BedZED Development | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Ventilation / Condensation | 6000 mm2 trickle + 1/30th floor area window / room. Intermittent extract to wet. 0.5 - 1 ac/hN. PSV to comply with BR IP 13 / 94. MVHR, or MEV only if comply with BR398 (air-tight < 4 ac/h50). Vent in CI calculation. | 0.5-1ac/hN. Wet extract humidity controls at 70% rh. | Passive, or MVHR, or assisted Passive.<br><br>Humidity vents. | Ventilation is a factor in the Total CO2 calc. | MVHR 30m3/h per person. (= 0.4ac/hN at SAP2001 occupancy of 3.12).<br><br>Underground pipes for vent air pre-heat? | MVHR 0.2 ac/hN thermal. | MVHR. Extract from wet. Incoming air from conservatory. Off in summer and windows open. | PSVHR | Different approaches to ventilation.<br><br>PassiveHouse, Vales, Hockerton and BedZED all have HRV.<br><br>BedZED PSHRV needs no power.<br><br>Underground pipes option in Passivehouse. |
| Heat recovery | BR398 has no value for heat exch.% | no value for heat exch.% | Heat>85% | | Heat>80% Latent HP | Heat >70% | Yes | Up to 70% EST, > 70% A to ZED | No HR value in UK regulations. |
| Fans / Pumps | BR398. In CI calc | | < 1W/l/s (= 0.28 Wh/m3) | In Tot CO2 calc | DC < 0.4 Wh/m3 | DC | DC | None | |

| Item | 2005 UK Building Regulations | UK Best Practice GPG79, GIL72 | UK Advanced GIL72 (based on GIR53 zero heat) | UK EcoHomes Standard | EU Passive-House | Vales Autonomous House | Hockerton Housing Project | BedZED Development | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Thermal Mass | No guidance | No guidance | High (no value) | No guidance | Passive houses with or without. | High: .784 MJ/K/m2 | High: 2.3 MJ/K/m2 | High | No thermal mass spec in UK building reg's. or passive house. |
| Passive solar | Glazing < 25% tfa. South glazing preferred.<br><br>CI calc includes solar gains | Living area to South.<br><br>Maximise South glazing.<br><br>Responsive heating.<br><br>CI calc includes solar gains | | Total CO2 kg/m2/yr | South glazing to give 40% space heat<br><br>Conservatory not specified. | Not optimised for solar gain (p54 'New Autonomous house') | Conservatory South facing. | Sunspace South unheated double glazed. 1100 kWh pa from heat store of passive gains. Winter sun exposed window > 8% tfa. | No clear position on sunspaces / conservatories.<br><br>BedZED spec glazing exposed to winter sun. |
| Space Heating systems and Controls | Fabric u depends on SEDBUK. Zone, time, boiler controls specified. Carbon Index. | CHeSS HC2 / HR2, SEDBUK > 82%, prog tmr, stats, zone, boiler controls, trv's Carbon Index. | CHeSS HC4 / HR4, Controls per BP | Total CO2 kg/m2/yr | <15 kWh/m2 pa. Heat Pump in incoming air. Subsoil Heat exchanger on air input for summer cool and winter heat (opt) | Wood stove backup. In centre of house. Temp allowed to drop to 15.5deg. | No space heating. Temp allowed to drop to 17 degrees. Electric fires as backup. | No primary space heat system. Radiator and towel rail on hw system (wood chp). Occasional use of elect. heaters. | GIL 72 'Best Practice' gives HC4 / HR4 v GPG 79 HC2? |

| Item | 2005 UK Building Regulations | UK Best Practice GPG79, GIL72 | UK Advanced GIL72 (based on GIR53 zero heat) | UK EcoHomes Standard | EU Passive-House | Vales Autonomous House | Hockerton Housing Project | BedZED Development | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Water Heating systems and Controls | Fabric u depends on SEDBUK. Zone, time, boiler controls specified. GPG302, GIL 59 (CHeSS). Carbon Index. | CHeSS HC2 / HR2, SEDBUK > 82%, prog tmr, stats, zone, boiler controls, trv's, high perf boiler. | CHeSS HC4 / HR4, Controls time and temp. | Total CO2 kg/m2/yr | Solar thermal, HP, District Heating, CHP.<br><br>Total energy spec < 42 kWh/m2 pa. | Minimise demand.<br><br>Electric heating w Heat Pump. (PV to offset electricity) | Air to Water Heat Pump to top of conservatory, large tank so HP run only when solar gain in winter. Immersion heater backup. | Wood CHP system gives district heating. | GIL 72 'Best Practice gives HC4 / HR4 v GPG 79 HC2. Minimise demand! Heat pumps popular. Hockerton conservatory heat pump! |
| Daylighting | Glaze > 1/15th floor per habitable room (not kitchen). | Maximise | 1.5, 2, 1 (pubic, kitchen, bedroom) | View of sky in all rooms. BS8206 | | | | Glaze area 16% of total floor area. | |
| Energy Efficient lighting and appliances | No guidance given? | 100% LEL, PIR's, A rated appliances. | 100% LEL, A rated appliances. | 100% LEL's, 100% A rated appliances. | High efficiency lights and appliances. Hot water to appliances to minimize heating. | 100% LEL, A+ rated appliances. | Low water and low energy appliances. 80% LEL's. | 100% LEL, A rated appliances. | UK Building regulations do not cover, CI only covers space and water heat. |

| Item | 2005 UK Building Regulations | UK Best Practice GPG79, GIL72 | UK Advanced GIL72 (based on GIR53 zero heat) | UK EcoHomes Standard | EU Passive-House | Vales Autonomous House | Hockerton Housing Project | BedZED Development | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Low water use | No guidance given? | | 4,6,50,16 | < 30 m3 / bed-space / yr internal. Rain collection for external. | | Rainwater capture and grey water recycle. 100% autonomous | Rainwater used for 100% supply to house. | Low water use inc dual flush. Rain collection across 50% site. | Minimise demand. Capture rain. Recycle grey. |
| Cooking | No guidance given? | | | A appliance | High efficiency. | Electric very low energy. | | Electric | |
| Clothes Dry | No guidance given? | | In house, vent with HR | Credits for clothes dry | | | | | |
| Supply options | CI calculation gives benefits for renewables. | | Balance emissions with PV, wind etc | Credits for renewable, CHP, HP etc Total CO2 kg/m2/yr | Offset all demands with renewable ownership | PV, HP, Wood stove. | HP, Wind. Some wood stoves in conservatories | PV (electric transport), Wood CHP. | |
| Metric | CI > 8, SAP | SAP > 100 CI =~8 | | EcoHomes scores for Pass, Good, Very Good, Excellent awards. CO2 kg/m2 pa. | Heating < 15kWh/m2 pa. Total < 42kWh/m2 pa. | | | SAP 150 | CI, SAP only cover space / hw heating. EcoHomes covers all carbon emissions but can get 'excellent' with poor energy score. |

### 3.1.1 Building Envelope and Construction

U-Values: The 2005 reg's, EcoHomes and UK Best Practice have similar insulation with wall u-values around 0.3 W/m2K. The Passive-House and UK Advanced standards and the Vales, Hockerton and BedZED examples all have increased insulation with wall u-values below 0.15 W/m2K.

Glazing: The Passive-House standard for triple glazing with u-values below 0.8 is significantly improved even on the Vales / Hockerton and BedZED examples although the double glazed conservatory which encloses all windows in the Hockerton case and a portion of the windows in the BedZED and Vales Autonomous House case) will improve the effective u-value of the enclosed glazed elements.

Thermal Bridging: The Passive House standard specifies the maximum linear thermal transmittance to be associated with thermal bridging. The UK guidelines give detailed guidance on avoiding thermal bridging but do not provide a specification. The UK Advanced standard suggests that a thermo-graphic survey should be considered. In the Vales, Hockerton and BedZED examples detailed consideration was given in the design stage to eliminating thermal bridging.

Airtightness: The Passive-House Standard and the UK Advanced both specify air-tightness as measured at 50Pa to be less than 1 ac/h. The building regulations give guidance on construction to achieve air-tightness but do not specify a value or require a test. In the design and construction of the best practice dwellings great care was taken to achieve air-tightness.

Breathing walls: The construction guidance provided in UK building regulation and energy efficiency best practice documents (and the documents referenced) show timber frame construction to require a vapor barrier and does not mention breathable wall construction.

### 3.1.2 Ventilation and Heat Recovery

The EU Passive-House standard specifies mechanical ventilation with heat recovery (MVHR) similar to that installed in the Vales Autonomous House and the Hockerton Housing Project. The ventilation rate specified by Passive house at 30m3/h per person (0.4 ac/h at SAP2001 occupancies) is similar to that assumed for the Vales Autonomous house of 0.45 ac/h which was based on Carpenters survey of advanced houses [49].

The Passive-House documentation specifies > 80% sensible heat recovery plus recommends a heat pump to extract latent heat and provide winter heating where required. The Passive-House standard also recommends the inclusion of underground pipes for pre-heating / cooling of ventilation air, these underground heat pipes are implemented in the Thening demonstration house [28].

The BedZED Housing has Passive Ventilation with Heat recovery which has the advantage of not requiring power for fans etc. The technical specifications of the BedZED PSVHR system were requested from ZEDfactory but up to this time had not been received, the heat recovery is reported in BedZED literature as 'up to 70%' [12], and > 70% [15].

The UK regulations and guidelines on ventilation recommend 0.5 to 1 ac/h to avoid condensation and specify the minimum amount of trickle ventilation and minimum size of window opening, they also specify minimum extraction rates from wet areas.

The UK regulations and guidelines allow mechanical extract (MEV), PSV or MVHR. Where PSV or MEV is installed humidity controlled vents are recommended (70% humidity). It is stated in the proposed 2005 regulations that 'continuously operated mechanical ventilation is no longer preferred due to sustainability considerations' presumably due to the electrical consumption. Guidelines are referenced for the installation of MVHR or MEV [31]. MVHR and MEV are only recommended where air-tightness of the dwelling is better than 4 ac/h at 50Pa, it is stated that typical dwellings are around 7 ac/h based on survey data.

No value for % Heat Recovery or the energy consumption is given in the UK regulations although these factors will be reflected in the SAP, CI and EcoHomes score. The UK Advanced standard does specify Heat Recovery > 85% and a tight specification on electrical fan power.

Where MVHR is used it appears the best way to minimize electrical power is to use DC fans.

### 3.1.3 Passive Solar and Thermal Mass

The UK 'Advanced' standard and the UK best practice examples all include high thermal mass. The UK Advanced standard does not specify the amount of the thermal mass.

The Passive-House and UK building regulations do not specify thermal mass.

There is general guidance in all standards to orient the glazing to the south to maximize solar gain. Solar gains through glazing are included in the SAP, CI and EcoHomes rating calculations. The Passive-House standard states that the design should allow the solar gain to cover 40% of the 15 kWh/m2 pa. heating requirements, the BedZED design calculation assumes that 1100 kWh pa (approx 6.4 kWh/m2 pa) is offset by solar gain.

The standards and guidelines do not specify conservatories although the three UK best practice examples all have them. The building regulations and SAP and CI calculations include the buffering effect of conservatories if they are unheated and outside the insulated envelope. If heated or within the insulation envelope then they are treated as a normal part of the building.

The BedZED guidelines in 'From A to ZED' specify that winter sun exposed glazing should be > 8% total floor area to achieve good capture of solar gains [15].

### 3.1.4 Space and Water Heating Systems and Controls

The UK building regulations, 'best practice' and 'advanced' standards in general recommend gas condensing boilers with effective control systems for space and water heating whereas the Passive-House and the UK best practice examples take different approaches.

The Passive-House standard specifies that there should be direct heating of the incoming air through the ventilation system with the option of using a heat-pump (which can also be used to extract sensible and latent heat from the outgoing air). The Passive-House standard also recommends that sub-soil heat exchangers are considered for heating or cooling ventilation air. For water heating the Passive-House standard recommends and provides examples of solar thermal, chp, district heating and heat pumps. The Passive-House standard requires that space heating is below 15 kWh/m2 pa. and that total energy import is below 42 kWh/m2 pa.

Vales Autonomous House, Hockerton and BedZED all have no primary heating system as their high mass construction combined with gains is designed to be sufficient. The Vales House does however experience temperatures as low as 15.5 degrees and a wood burning stove is used to provide backup heating (around 6.4 kWh/m2 pa). The Hockerton houses on occasion require the use of electric heaters in coldest periods or periods where gains are insufficient. BedZED uses occasional electric fires and the water heating system has a heated towel rail (radiator) and a radiator built into the water storage tank which can be operated when required.

Hockerton and the Vales Autonomous house both specify large water tanks and air to wet heat pumps for water heating, advantage is taken of solar gain to the conservatory in the Hockerton case.

BedZED utilizes a wood fuelled CHP system for electricity and hot water production (and backup heating, see above).

It is worth noting that the approach in the Vales House was to greatly minimize water use and therefore reduce the water heating demand.

### 3.1.5 Lighting, Appliances and cooking

The 2005 UK regulations do not give guidance on lighting and appliance energy consumption. The EcoHomes energy section does consider total $CO_2$ including electrical consumption and take into account the amount of low energy lighting and appliances installed.

PIR's are recommended in the UK 'Best Practice' standard in GPG79. The Passive-House standard recommends hot water supply to appliances to minimize electrical heating. Low water using appliances can also reduce the electrical power consumption.

### 3.1.6 Water Use and clothes dry

The EcoHomes standard awards points for low water use and rainwater collection for external uses. The UK 'Advanced' standard and the UK best practice examples all consider techniques to minimize water requirements. Credits given for clothes dry in EcoHomes and required by UK 'Advanced'.

### 3.1.7 Supply technologies

The Passive House and UK 'Advanced' Standard recommend offsetting net energy import and achieving net zero CO2 with on-site or off-site renewables e.g. Wind turbine, PV installation, Green Tariff.

As previously discussed a variety of supply options can are being used to meet the space and water heating demands. Similarly there are a variety of methods employed to meet the electricity demands renewably e.g. PV, Wind and Wood fired CHP.

### 3.1.8 Metrics

The Passive-House standard uses the kWh/m2 pa value for space heating and total energy to measure performance. These metrics capture the total energy use in the operation of the dwelling (apart from food) including lighting and appliances. The kWh/m2 metric does not appear to consider factors such as electricity generation efficiencies etc but does state that energy imports should be offset by renewables.

In contrast the in the case of the UK Building regulations, SAP and CI only consider the space and water heating energy requirements and assume a typical electrical load in space heat gains calculations only. SAP is linked to the price of the fuel and CI is linked to the primary fuel required including electricity generation efficiencies.

The UK EcoHomes standard does award points for total CO2 and also building envelope improvement over building regulations. The total CO2 metric is captures all energy use for space and water heating, lighting and appliances, captures the contributions due to renewables and captures the electricity generation efficiencies.

**3.2 Quantitative analysis of performance of standards and best practice examples by calculation of key metrics**

In order to quantify the performance of dwellings built to the different standards a range of metrics were calculated for each.

The primary metrics evaluated are:

- The EcoHomes Energy Score (Points for Ene1 to Ene5)
- The annual CO2 released due to operation (kg/m2 pa) (Similar to EcoHomes Ene1)
- The Carbon Index Score (0-10)
- The SAP2001 Rating (0-120)
- The energy consumed due to space heating (kWh/m2 pa)
- The total annual energy consumed due to operation (kWh/m2 pa)

The standards and guidelines that were evaluated were:

- A typical house built to UK 1995 building regulations
- A typical house built to the proposed UK 2005 building regulations
- A house built to the UK Best Practice guidelines (GIL72, GPG79)
- A house built to the UK Advanced standard (GIL72) with gas heating
- A house built to the UK Advanced standard with direct electric heating
- A house built to the UK Advanced standard with electric heat pump heating
- A house built to the UK Advanced standard with renewable energy offsetting all heating and power (Autonomous House).
- A house complying with the Passive-House standard
- A house built to Vales Autonomous House standard with grid / mains supplies.
- A house based on a Hockerton Housing Project dwelling with electrical grid supplies.
- A BedZED type 3 bedroom dwelling with standard grid / mains supplies.
- A BedZED type 3 bedroom dwelling with wood CHP supply.

The calculation results are shown in the table below, the following graphs and associated dialog illustrate the key points.

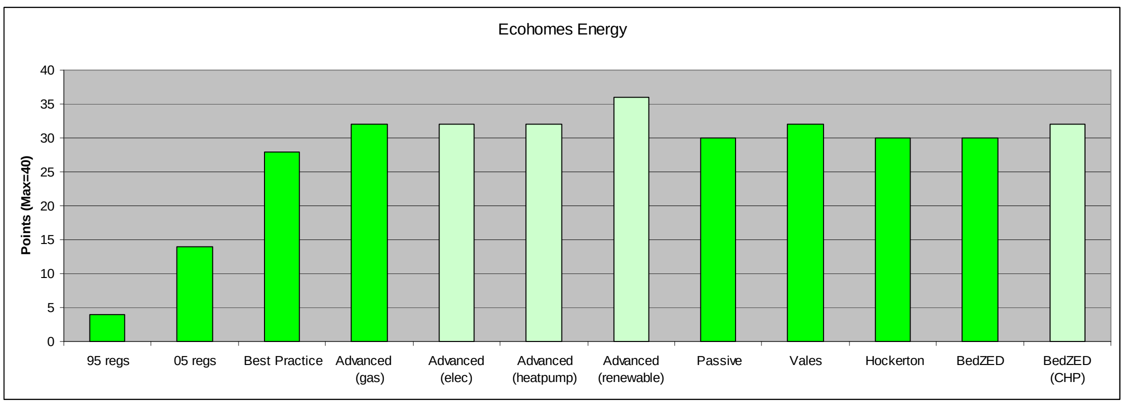
| | Advanced (gas) | Advanced (elec) | Advanced (heatpump) | Advanced (renewable) | BedZED | BedZED (CHP) |
|---|---|---|---|---|---|---|
| Ecohomes Energy (from 40) | 32 | 32 | 32 | 36 | 30 | 32 |
| Elec lights / apps / fans kWh/m2 pa. | 18 | 18 | 18 | 18 | 18 | 18 |
| Total Space heat demand kWh/m2 pa. | 23 | 21 | 8 | 8 | 17 | 17 |
| Total energy demand kWh/m2 pa. | 75 | 69 | 41 | 43 | 60 | 62 |
| SAP | 122 | 76 | 129 | 300 | 171 | 162 |
| CI (1-10) | 10 | 10 | 10 | 10 | 10 | 10 |
| CI calculated | 10 | 8 | 12 | 20 | 11 | 17 |
| Space+water CO2 kg/m2 pa. | 10 | 19 | 7 | 0 | 7 | 2 |
| Total CO2 kg/m2 pa. | 18 | 26 | 15 | 0 | 15 | 2 |
| Total Space +water heating £ pa | 100 | 239 | 90 | 0 | 54 | 60 |
| Total £ pa | 201 | 356 | 207 | 0 | 169 | 175 |

The sources and assumptions made in calculating the above data were as follows:

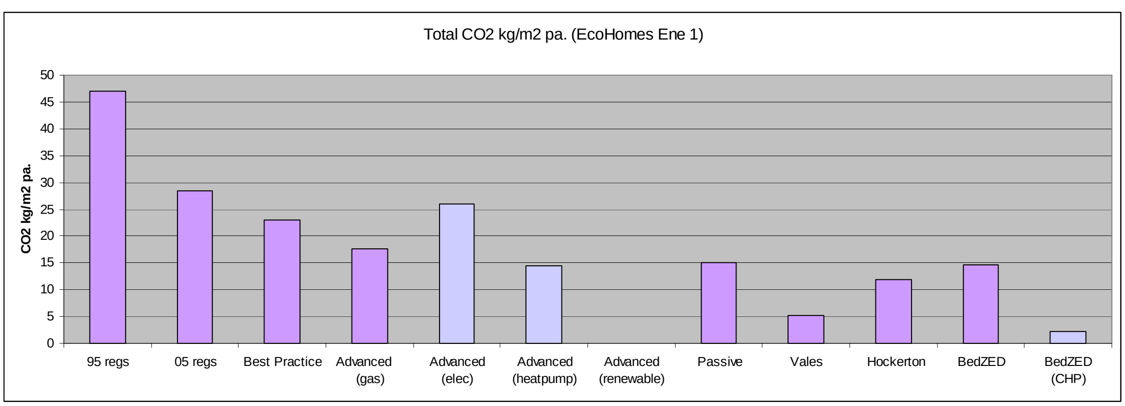
UK 2005 building regulations: electrical demand – EcoHomes equation with 0% energy efficient lights, space and water back calculated from CI.
UK Best Practice guidelines (GIL72, GPG79): electric – EcoHomes equation with 100% energy efficient lights, space and water heating back calculated from CI = 8.6.
UK Advanced standard (GIL72) with gas heating: electric demand from Hockerton /BedZED, space and water heat from SAP2001 spreadsheet (below)
UK Advanced standard with direct electric heating: same as above but with heating efficiency adjusted.
UK Advanced standard with electric heat pump heating: same as above but COP=3.
UK Advanced standard with renewable energy offsetting all heating and power: 0 CO2
Passive-House standard: Space heat and total energy use from PH spec., electrical demand from Hockerton/BedZED.

Vales Autonomous House standard with grid / mains supplies: as reported in New Autonomous House, wood stove fuel assumed as gas.
Hockerton Housing Project dwelling with electrical grid supplies: data from NPP119 with HP and low energy freezer.
A BedZED type 3 bedroom dwelling with standard grid / mains supplies: data on demands from BedZED documents . Electrical demand converted using SAP2001 occupancy.
A BedZED type 3 bedroom dwelling with wood CHP supply: same as above but using SAP2001 wood emissions factor and CHP calculations.

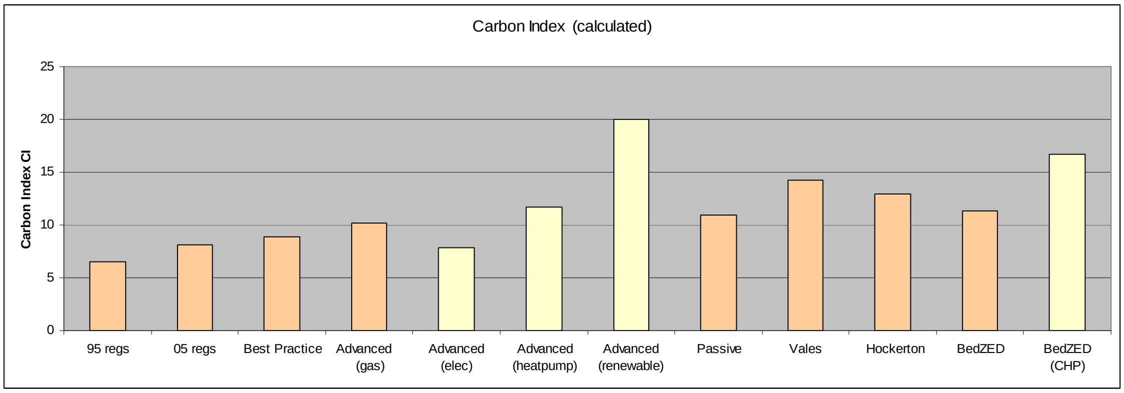
The graph below shows the Ecohomes Energy section score. It can be seen that this metric clearly shows the improvement from 1995 regulations through the 2005, Best Practice and Advanced standards. The scoring however does not differentiate strongly between the different advanced houses or the different supply options, this is due to the fact that the scoring in Ene1 has only a 10 kgCO2/m2 pa resolution below 20 kg/m2 pa. It is worth re-stating that the energy section of the EcoHomes only contributes 21% of the overall EcoHomes assessment.



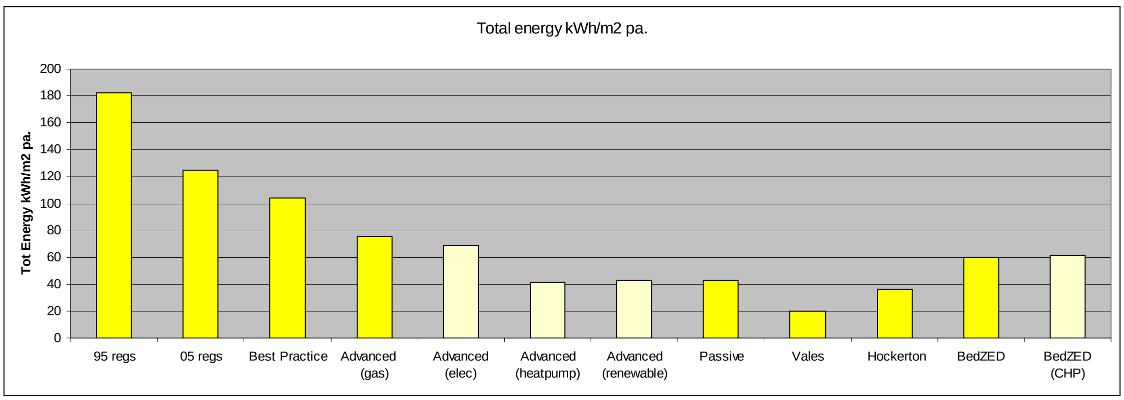

The total annual CO2 due to operation of the dwelling is shown in the graph below. This metric again reflects the improvement in building standards but also differentiates between the different supply options in terms of their differing impact on CO2 release. It can be seen that the Advanced standard building can perform worse than a Best Practice building if the space and water heating is switched from gas to electricity. Also it can be seen that the wood based CHP system in BedZED or an entirely renewable supply system (or fully offset of supply) can have a large impact on CO2.

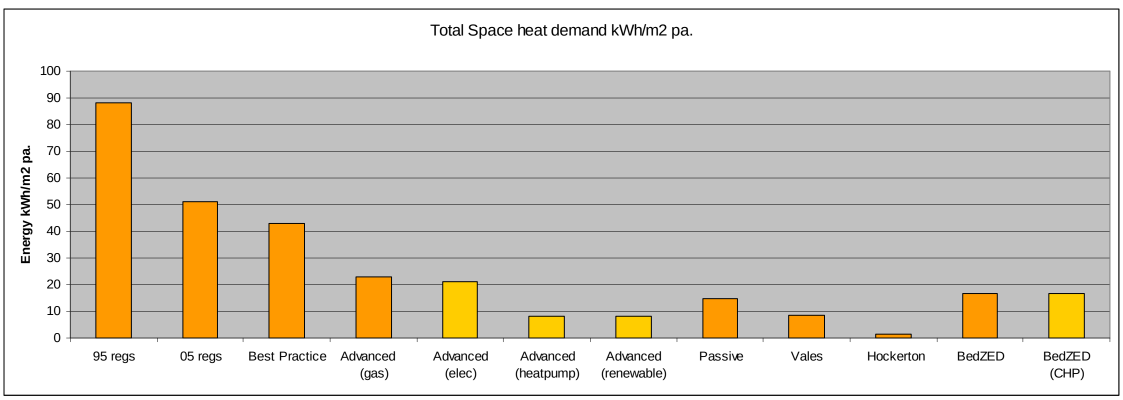



The Carbon Index (below) does reflect the impact on the different supply technologies on the space and water heating energy use but does not show the impact of alternative supplies on the CO2 emissions due to electrical energy use. The Carbon Index values shown are the calculated values from the SAP2001 worksheet, as the maximum of the Carbon Index range is 10 then this score would be allocated to all of the advanced houses and the Carbon Index would not differentiate between them. It would seem logical to extend the Carbon Index range further (as was done for the SAP range).

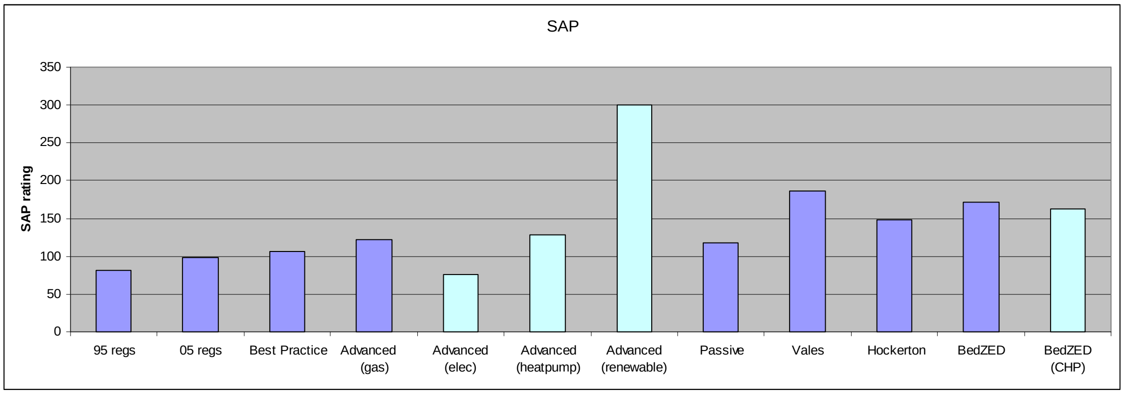



The total annual energy use per metre squared and the total energy used for space heating do not reflect the different environmental impacts and CO2 emissions of the different fuels. The energy used for space heating metric is an indicator of whether a primary heating system (e.g. gas boiler plus wet system) is required or economic.




The SAP metric which has a normal maximum of 120 does not reflect the CO2 emissions or the energy for lighting, appliances or cooking. It is linked to the costs of the fuel used.


SAP
SAP rating
350
300
250
200
150
100
50
0
95 regs
05 regs
Best Practice
Advanced (gas)
Advanced (elec)
Advanced (heatpump)
Advanced (renewable)
Passive
Vales
Hockerton
BedZED
BedZED (CHP)

SAP Calculation - Advanced (gas)

| | | | |
|---|---|---|---|
| Ground floor area | m2 | 45 | |
| Number of floors | num | 2 | |
| Room height | m2 | 2.4 | |
| Dwelling volume | m3 | 216 | |
| Number of chimneys | num | 0 | 40m3/hr/chimney |
| Number of flues | num | 0 | 20m3/hr/flue |
| Number fans or passive vents | num | 0 | 10m3/hr/fan or vent |
| Infiltration ch/f/f | ac/h | 0 | |
| Number stories | num | 2 | |
| Infiltration stories | ac/h | 0.1 | |
| Structural infiltration | ac/h | 0.1 | 0.25 for steel / timber, 0.35 for masonry |
| Suspended wooden floor | ac/h | 0 | 0.2 unsealed, 0.1 sealed, or 0 |
| Draught lobby | ac/h | 0 | 0.05 if no draught lobby, else 0 |
| Percent windows draught stripped | % | 200 | |
| Window infiltration | ac/h | -0.15 | |
| Infiltration rate | ac/h | 0.05 | |
| or if press test done then q50/20+[10] | | | |
| Sheltered sides | num | 2 | |
| Shelter factor | num | 0.85 | |
| if MVHR eff ach rate | ac/h | 0.2125 | if no MVHR add 0.33 to this! |
| if natural ventilation ach rate | ac/h | 0.0425 | |
| if nat vent rate < 1 then nat vent modified | ac/h | 0.500903 | occupants open windows if ac/h <1 |
| final vent rate MVHR or Nat | ac/h | 0.500903 | assumes natural vent |

| Element | Area(m2) | U(W/m2K) | AxU(W/K) | |
|---|---|---|---|---|
| Doors | 3 | 1.5 | 4.5 | |
| Windows | 13.5 | 1.5 | 18.225 | factor of 0.9 assumes use of curtains |
| Ground floor | 45 | 0.1 | 4.5 | |
| Walls | 112 | 0.15 | 16.8 | |
| Roof | 45 | 0.08 | 3.6 | note: if conservatories garages etc then more detail |
| Other | 0 | 0 | 0 | needed to capture the buffer effects etc. |
| Total | | | 47.625 | Fabric loss |

| | | | |
|---|---|---|---|
| Ventilation heat loss | W/K | 35.70437 | Vent loss |
| Heat loss co-eff (Vent+Fabric) | W/K | 83.32937 | |
| Heat Loss Parameter HLP | W/m2K | 0.925882 | |
| Occupancy N | num | 2.8422 | calculated, floor area < 450m2 (8 if TFA>450m2) |
| Hot water energy req't | GJ/yr | 4.979428 | calculated, also tables available added factor of 0.7 for low water apps |
| Distribution loss | GJ/yr | 0.878723 | calculated, also tables available added factor 0.7 |
| Water storage volume | Litres | 120 | |
| Volume factor VF | num | 1 | from table, also calc avail |
| Water storage loss factor | GJ/yr/litre | 0.0026 | from table, factory insulated 150mm |
| Energy lost from water storage | GJ/yr | 0.312 | 86.736 kWhpa 672.768 |
| Area of solar panel | m2 | 0.001 | solartwin |
| solar energy available | GJ/yr | 0.0013 | assumes 1.3GJ/yr per m2? = 360kWh/m2 |
| load ratio | num | 3830.329 | |
| solar input | GJ/yr | 0.0013 | |
| Primary water circuit loss | GJ/yr | 1.3 | boiler, uninsulated primary, boiler stat, table 3 |
| Output from water heater | GJ/yr | 7.46885 | |
| Water heater efficiency | % | 86 | |
| Energy required for water heating | GJ/yr | 8.68471 | |
| Heat Gains from water heating | GJ/yr | 3.237435 | |
| Internal gains-lights,apps,cook,meta | W | 457.2882 | calc based on TFA and N, for TFA < 282m2, also 10W heating syst pump |
| Water heating gains in W | W | 102.6591 | ignores low energy lighting! add factor of 0.85 for Eeff / daylig |
| Total internal gains | W | 559.9472 | |

| Solar Gains - element orientation | F-access | Area(m2) | Flux | Gains(W) |
|---|---|---|---|---|
| North | 1 | 5 | 13 | 65 |
| East | 1 | 0 | 22 | 0 |
| South | 1 | 8.5 | 32 | 272 |
| West | 1 | 0 | 22 | 0 |
| Rooflights | 1.3 | 0 | 13 | 0 |
| Total solar gains | | | | 337 |

| | | | |
|---|---|---|---|
| Total gains | W | 896.9472 | |
| Gains to loss ratio GLR | K | 10.76388 | |
| Utilisation Factor | num | 0.82 | table 7, more gains less utilisable. |
| Useful gains | W | 735.4967 | |
| Mean internal temperature of living room | C | 19 | table 8, depends on HLP |
| Temp adjust for controls | C | -0.6 | table 4e |
| Adjustment for gains | C | 0.965276 | |
| Adjusted living room temp | C | 18.63472 | |
| Temp diff between zones | C | 0.6 | table 9, depends on HLP, controls |
| Living area fraction | num | 0.2 | living room area / total floor area |
| Rest of dwelling fraction | num | 0.8 | |
| Mean internal temperature | C | 18.15472 | |
| Temp rise from gains | C | 8.82638 | |
| Base temp | C | 9.328344 | |

# Chapter 4:

# Sustainable housing standards and metrics; discussion, key issues and recommendations

### 4.1 Sustainability metrics

Personal energy use is around 30% in housing, 30% in transport and 40% in food [2]. Housing can have a large impact on the transport and food energy use as the need for personal transport and the need to buy and transport food depends on the availability and proximity of workspaces and food production and procurement facilities. The embodied energy in packaged foods transported from distant countries is very large compared to locally self produced food. Transport energy is impacted by the availability of cycle storage facilities, the proximity of public transport and the proximity to social facilities such as schools, nurseries, café's, community centres, sports facilities etc.

It can be seen from the table below that the impact of space and water heating on energy use continues to be large but that the impact of lights, appliances and cooking is increasing in relative terms.

| | 1995 reg's | | 2005 reg's | | Advanced (gas) | | Advanced (hpmp) | |
|---|---|---|---|---|---|---|---|---|
| | kWh/m2 | % | kWh/m2 | % | kWh/m2 | % | kWh/m2 | % |
| Space heating | 88 | 49% | 51 | 41% | 23 | 32% | 7 | 19% |
| Water heating | 52 | 29% | 42 | 34% | 28 | 38% | 8 | 22% |
| Lights and appliances | 33 | 18% | 24 | 20% | 18 | 25% | 18 | 49% |
| Cooking | 7 | 4% | 6 | 5% | 4 | 5% | 4 | 11% |
| Total kWh/m2 pa. | 180 | | 123 | | 73 | | 37 | |

Also as the operational energy of housing is decreasing then embodied energy over the life of the building materials becomes more significant.

The increasing trend towards air-tight dwellings puts increased emphasis on the avoidance of pollutants, irritants or toxins in the internal environment [50]. Occupants will increase ventilation if they feel air is stale or unhealthy and this will negatively affect energy use.

The EcoHomes standard covers these broad aspects of sustainability well and it is justifiable that it is being adopted as the way forward by Government, Housing Associations and planning officials [42].

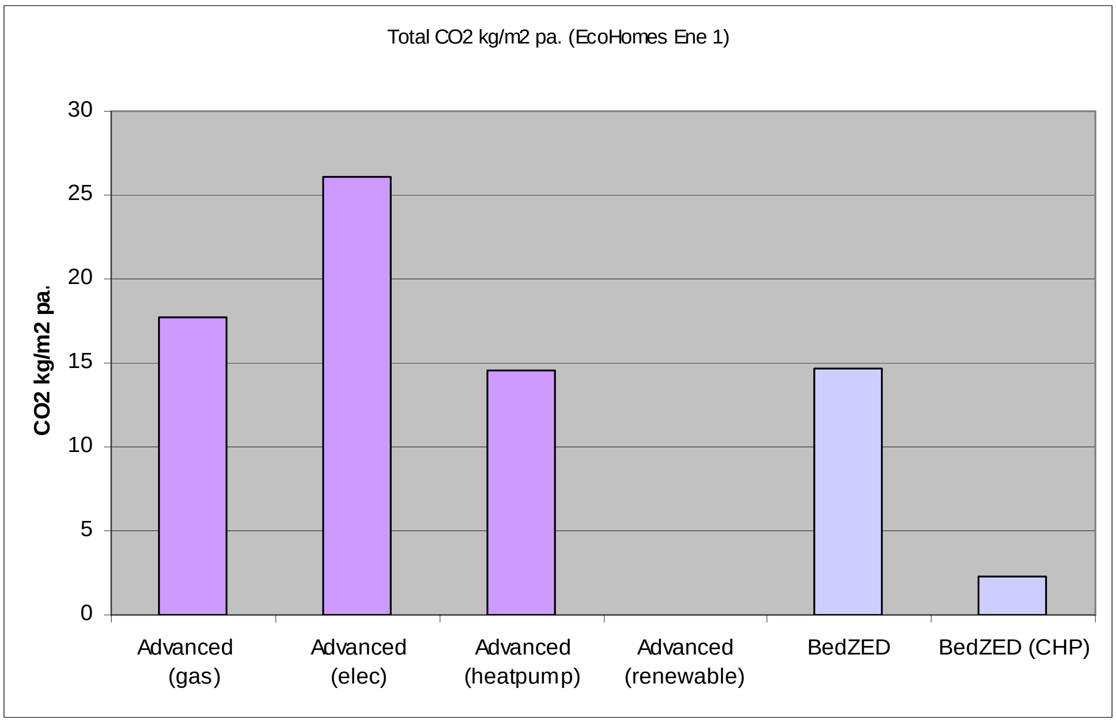
The broad span of the EcoHomes standard is of benefit but also can be an area of weakness in terms of energy efficiency as it is possible to achieve an 'Excellent' rating (>70%) without achieving any points in the 'Energy' section which accounts for only 21% of the EcoHomes score. It could be argued that this would still be an acceptable result as the house would have to conform to at least the building regulations however the regulations requirement of CI > 8 is not 'Excellent' in energy terms and does not include the impact of energy use for lights and appliances other than as a source of gains.

The energy section of EcoHomes (Ene1-Ene5) and also the Passive-House standard both cover more than just the space and water heating component of the energy required to operate the dwelling. The EcoHomes Ene1 section intends to cover all operational energy use (although cooking energy may not be covered by the lights and appliances BREDEM equation used?) and quantify the associated CO2 impact. The Passive-House standard just states a maximum number of 42 kWh/m2 pa. as the maximum operational energy requirement.

The ultimate intent of the Passive-House movement is to offset all energy required with renewable resources and potential solutions have been demonstrated e.g. CHP, wind, PV etc [28] however in the current time it is felt that a metric should be able to reflect the variations in CO2 emissions and pollution associated with the primary energy production and so the EcoHomes metric has an advantage.

The EcoHomes energy section score (points allocated for Ene1 to Ene5) follows well the improvements in energy use from 1995 regulations through to Best Practice housing but then has poor resolution for more advanced housing due to the coarse scale applied for point allocation below 20 kWh/m2 pa .

The EcoHomes Ene1 metric CO2 kg/m2 pa. appears to be the best metric to represent the operational energy performance of a building as this most directly represents the energy used and the polluting effect of different supply options. Renewables such as the BedZED type house with wood fuel CHP (shown below) look best to this metric.




In summary it would be reasonable to continue to establish the EcoHomes standard and integrate it into the building regulations and planning process. It is recommended that the ratings are enhanced (e.g. Excellent 1-5 stars?) to recognise scores greater than 70%. It is recommended that the EcoHomes ‘Energy’ standard (Ene1 – Ene5) is revised to allow better resolution for advanced houses. It is recommended that the EcoHomes Ene1 CO2 kg/m2 pa. becomes the standard metric for operational energy use in housing in preference to SAP and CI as it covers heating, lighting and appliances and includes the environmental impact of the energy production process, one area of concern is the BREDEM based calculation of the CO2/m2 pa. metric and its treatment of cooking and thermal mass.

### 4.2 Supply Options

The UK Advanced and Passive-House standards both call for energy demands to be offset by renewable energy supplies to achieve net zero carbon.

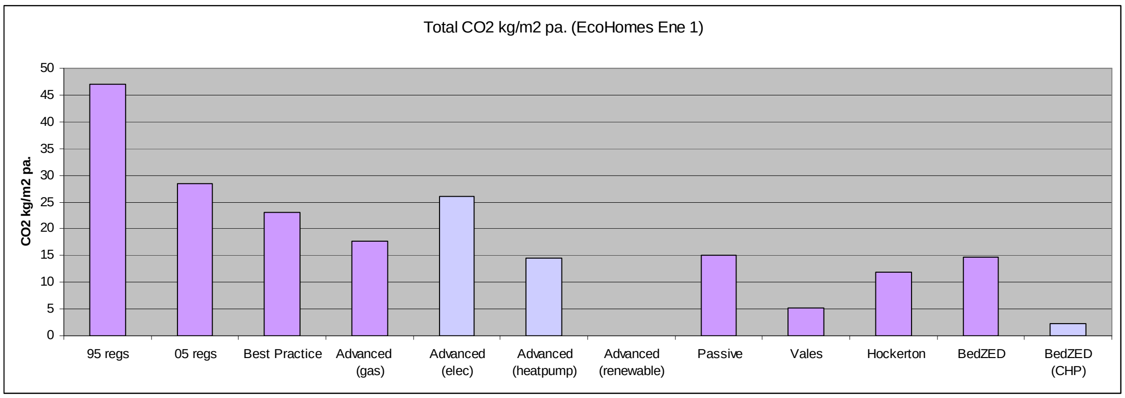
The examples of best practice do this in different ways, the Vales Autonomous house utilizes a large PV array to offset electricity demand, the Hockerton Housing project incorporates a wind turbine, the BedZED development incorporates large PV arrays and also a wood fueled CHP system.

The Passive-House standard, the Vales Autonomous House and the Hockerton Housing project all incorporate heat pumps as a way of minimizing electricity used for electric heating of space or water.

The table below shows the impact of heat pumps in housing built to the UK Advanced standard. The CO2 performance of the electric heat pump supplied with grid electricity (standard grid tariff) is comparable to that of a gas heating system. Where there is electricity available from a renewable source then the CO2 performance is very much improved.

| | Advanced (gas) | | Advanced (elec) | | Advanced (hpmp) | | Advanced (ren) | |
|---|---|---|---|---|---|---|---|---|
| | kWh/m2 | CO2kg/m2 | kWh/m2 | CO2/m2 | kWh/m2 | CO2/m2 | kWh/m2 | CO2/m2 |
| Space heating | 23 | 4.5 | 21 | 8.7 | 7 | 2.9 | 7 | 0 |
| Water heating | 28 | 5.4 | 24 | 9.9 | 8 | 3.3 | 8 | 0 |
| Lights and appliances | 18 | 7.5 | 18 | 7.5 | 18 | 7.5 | 18 | 0 |
| Cooking | 4 | 0.8 | 4 | 1.7 | 4 | 1.7 | 4 | 0 |
| Total (annual) | 73 | 18.1 | 67 | 27.7 | 37 | 15.3 | 37 | 0 |

The wood fuelled CHP system at BedZED (see below) is extremely beneficial as the wood is seen as carbon neutral except for the impact of processing and transportation [32]. CHP can be used to displace grid electricity which has the highest CO2 impact.




Offset of the energy demand has high impact but the method utilized appears to be situational and depend on local factors.

Guidelines and examples exist showing how to evaluate and implement various individual sustainable supply options [51,52] however no process for selecting the best combination of options was found in the literature. Strathclyde University ESRU's MERIT software [53] is under development which may address this gap. (also see further work section in this thesis).

**4.3 Building Envelope, Glazing, Materials, Construction, Thermal Mass and Solar Gain.**

The super-insulation recommended to achieve the sub 0.15 W/m2K u-values in the Advanced houses has the negatives of reducing available floor area (by up to 7.5% in typical detatched Swedish home [ 29]) and also of pushing the construction industry beyond the standard wall tie lengths [12,8].

Avoidance of thermal bridging and achieving air-tightness are other challenges for the UK construction industry. The construction guidance given in the current UK best practice guides is a step in the right direction but it is recommended that a specification for thermal bridging is established and that thermal performance is verified by thermo-graphic means, also it is recommended that a specification for air-tightness is established and a 50Pa pressure test made mandatory.

The construction approach recommended in the EEHBPp UK best practice guidelines and demonstrated in the Vales, Hockerton and BedZED developments is high thermal mass construction.

This approach is in conflict with the Finney article [23] in which he states that high thermal mass always requires at least 10% more heating energy. Finney sides with the low embodied energy philosophy put forward by CAT and Findhorn [6,4]. CAT's sustainable building publication questions whether the thermal mass of the plasterboard in a timber frame house is sufficient mass to provide effective utilization of solar and other gains [6] and suggests that clay or earth mass elements should be used if additional mass is required.

The Australian and New Zealand investigations into thermal mass appear to show its effect as small compared to other factors and reducing with increasing latitude [55,56].

The Passive-House demonstration houses appear to have reducing thermal mass as latitude increases and the thermal mass requirement appears to be driven by cooling needs.

The Green Guide to Housing Specification which is based on life cycle analysis (LCA) of environmental impact gives more ‘A’ ratings - and hence more EcoHomes materials points - to thermally light floors and roofs while both high and low thermal mass walls can get an ‘A’ rating, so in general this would drive away from a high mass construction although in the case of multi-occupant dwellings the EcoHomes materials points benefit for low mass may be offset by increased sound insulation points for the high mass flooring. The LCA is carried out over 60 years while the lifespan of housing could be expected to be much longer especially in the case of heavyweight construction.

The BREDEM model does not consider thermal mass as a significant factor [41] and does not include thermal mass in its calculations (although this author has suggested how thermal mass could be factored in, see section on BREDEM model). The UK building regulations and the Passive-house standard do not explicitly specify thermal mass.

The Vales Autonomous house appears to perform well although it is not designed to exploit solar gains, the argument put forward by the Vales is that the solar gains cannot be relied on in UK winter and are not required to achieve ‘zero heating’. The Hockerton, BedZED, Passive-Houses and SAP 2001 calculation all consider solar gains to be important.

There are clearly conflicting views on the role of thermal mass and solar gain in sustainable housing in the UK and it appears that an investigation across UK climates is required (this is further investigated in section 2 of this thesis).

**4.4 Ventilation**

The UK current guidelines and even the Advanced standard are considerably less proscriptive (in that they allow Passive Stack, Mechanical Extract or Mechanical Ventilation) compared to the Passive-House specification which specifies MVHR. The Vales and Hockerton houses have MVHR similar to the Passive-House standard and BedZED has a passive stack ventilation system with heat recovery (PSVHR).

Negatives for MVHR system in the UK have been the maintenance requirements, the noise of the fans and the energy required to operate them.

Further investigation of the energy saving from MVHR is carried out in section 2 of this thesis.

### 4.5 Summary of conclusions on sustainable standards and metrics

The Ecohomes assessment scheme is found to provide a good rating for overall sustainability but weaknesses have been identified.

The first area of weakness is that the maximum award of ‘Excellent’ is achieved for a score of 70%, this allows a development to be ‘Excellent’ which scores 0% for the energy section. It is proposed that the EcoHomes ‘Excellent’ criteria is differentiated by the addition of 1 to 5 stars for scores beyond 70% i.e. ‘Excellent 5-star’ rating if > 95% etc.

The second improvement would be to improve the resolution of the points awarded for performance below 20 kgCO2/m2 pa to allow differentiation of more advanced houses, at present they fall in 10 kgCO2/m2 pa buckets.

The third suggested improvement would be to replace the SAP and CI metric with the EcoHomes Ene1 calculated CO2 kg/m2 pa. metric as this would allow the environmental impact of lights, appliances and cooking to be included.

The impact of energy supply technologies on sustainability is shown to be large, the approaches taken in the different examples and standards are discussed however there is no clear consensus on the best way to achieve optimum.

The conflicting views on the importance of thermal mass, solar gain, and ventilation method for sustainability in housing have been highlighted. An investigation using ESP-r into the importance of thermal mass, insulation and ventilation across UK climates and occupancies has been the focus of the second half of this thesis.

# Chapter 5:

# Introduction to the role of thermal mass, insulation, and ventilation in sustainable housing and the importance of climate and occupancy

### 5.1 Introduction

The UK building regulations have been regularly tightened from an energy performance perspective since the early 1990's. The latest revision of the regulations is planned to be released in 2005 and details of the proposed specifications [30] are given in the table below. Associated with the building regulations are a number of BRE and BS documents which give detailed advice on how to construct to meet the regulations and these are also updated regularly.

In addition to the minimum standards provided in the building regulations, the UK Housing Energy Efficiency Best Practice Program (HEEBPP) provides guidelines on best practice for energy efficient and sustainable housing that apply to both new build and refurbishment.

The HEEBPP general information leaflet GIL 72 "Energy efficiency standards – for new and existing dwellings" [35] published in 2002 documents 'Best Practice' and 'Advanced' standards, details from the Advanced standard are given the table below. The advanced standard is stated as being based on the previously documented 'Zero Heating' standard from HEEBPP general information report GIR 53 which is a high thermal mass construction where all floor, wall and ceiling surfaces are exposed concrete [9]. GIL 72 gives the incremental build costs for best practice and advanced standards compared to building regulations for both timber-frame and masonry constructions. Summaries of GIL 72 and GIR 53 are given in section 1 of this thesis.

In Europe the 'Passive House' standard has been the subject of EU THERMIE project BU/0127/97 'Cost Efficient Passive Houses as European Standards' (CEPHEUS). More than 1000 houses have been built to the passive house standard, the CEPHEUS project has monitored 250 passive houses across Switzerland, Germany, Austria, France and Sweden [28]. The passive house target is to keep total final energy demand for space heating, domestic hot water and household appliances below 42 kWh/m2 pa and space heating below 15 kWh/m2 pa. There is no specification relating thermal mass, passive houses have been realised in both thermally light and thermally heavy constructions [28]. Details from the passive house standard are shown in the table below and a summary of the passive house standard is given in section 1 of this thesis.

| Building standards | UK 'Advanced' Standard | Passive-House Standard | Proposed 2005 Building Reg's |
|---|---|---|---|
| Wall U | 0.15 | 0.1 | 0.3 |
| Floor U | 0.1 | 0.1 | 0.25 |
| Roof U | 0.08 | 0.1 | 0.16 |
| Door U | 1.5 | 0.8 | 2 |
| Glazing U | 1.5 | 0.75 | 2 |
| Air-tightness | 1ac/h@50Pa | 0.6ac/h@50Pa | No spec |
| Ventilation | PSV or a-PSV or MVHR | MHRV | Extract or PSV or MVHR or MEV |
| Thermal Mass | High (GIL53) | No spec | No spec |

Several Passive Houses are included in the IEA Sustainable Solar Housing demonstration house brochures [29]. The demonstration houses have a range of constructions from thermally light timber frame, through light frame with concrete flooring to the heaviest which have multiple high mass elements. In general the use of increased solar mass in these demonstration houses appears to be driven by the requirement for night cooling by cross ventilation in summer. The IEA demonstration houses in Tuusniemi in Finland (lat 62N) are entirely lightweight construction. The houses in

Goteborg in Sweden, Thening in Austria and Dinkton in Switzerland have thermally low mass constructions with high mass concrete floors (the Thening house also has underground air pipe ventilation cooling). The Hanover, Germany terrace housing has low mass external walls but high mass internal and cross walls. The southern Switzerland demonstration house has a thermally massive construction similar to the UK Zero Heating standard and the BedZED, Hockerton and Autonomous houses. In general the amount of thermal mass increases the more southerly the location driven by summer cooling.

Professor Brenda Vale and Dr Robert Vale were the authors of the UK GIR 53 which put forward the argument for the super-insulated high mass ‘Zero Heating’ standard which is the basis of the more recently proposed UK ‘Advanced’ standard. The Vales had previously designed, built and lived in the super–insulated, high thermal mass ‘Autonomous House’ in Southwell in the Midlands and their experiences are documented in ‘The New Autonomous House’ [8]. The Vales quote New Zealand experience that heating demand was reduced by 40% by the addition of thermal mass to timber frame houses through concrete floors. Due to the site constraints the Autonomous House was built in the form of a traditional house and was not oriented to exploit solar gains. The Autonomous House is reported as requiring around 1000kWh space heating (6.4 kWh/m2 pa) over the heating season, this was supplied from a wood burning stove.

The Vales were subsequently the architects of the Hockerton Housing project near Nottingham which is another successful example of high thermal mass low energy housing [10,11]. The Hockerton Houses are earth sheltered and oriented to fully exploit solar gains and are reported to require only occasional use of radiant fires for space heating.

Beddington Zero Energy Development (BEDZED) 20 miles south of London was designed by Bill Dunster Architects to be super-insulated and high mass and maximise solar gain through glazing primarily to the south. A feature of this development is the integration of workspaces into the development which increases occupancy [12]. The BEDZED dwellings are reported to require only 16 kWh/m2 pa space heating [13,14,15]. BedZED is supplied with hot water from a wood burning CHP system and the hot water system supplies a towel heater in the bathroom and a small radiator that can be used in extreme conditions.

David Finney recently reported in ‘Building for a Future’ on his experiences of design, building and living in his own high mass and low mass low energy homes [23]. The high and low thermal mass houses are built to approximately the 2002 building regulations (England) with walls having a U-value of 0.35 W/m2K. He sites references from 1974 and 1980 and states that “computer simulation has suggested that, overall, a high inertia house will use at least 10% more energy, dependent on the level of insulation”. He reports his experience that in the high mass house “more fuel was clearly required to ‘charge up’ and keep the high thermal capacity walls ‘filled’ if they were not to act as cold sinks”.

The Findhorn Foundation at their eco-village in the north of Scotland have practical experience of super-insulated thermally light (timber frame, straw-bale) and thermally heavy (earthship) constructions [4]. Anecdotally their experience of the earthship was that it was too cold for use as a dwelling and currently houses their gas district heating system, it was not clear what caused the cold initial temperatures.

There have been several investigations published [56,57] on the influence of thermal mass and insulation on space heating (and cooling) requirements across the New Zealand temperature zones (latitudes 32 to 47) which show a beneficial impact of thermal mass that decreases as the climate becomes further from the equator. The UK climate zone extends beyond the latitudes covered by these studies (UK latitudes 49 to 62).

The higher embodied energy and heat required to dry-out high thermal mass houses are concerns although it has been shown that in the whole life energy cost analysis the operational energy demand is the most important factor [13,58].

The objective of this study is to investigate the key factors driving space heating and cooling energy and to quantify the relative impact of insulation, thermal mass, orientation, occupancy / gains and climate for UK low energy housing. The results should be applicable to other similar climate areas.

### 5.2 Simple calculation model

Based on the arguments and calculations outlined in chapter 4 of the Vales 'New Autonomous House' [8] a simple spreadsheet model was constructed that verified the results given and also allowed further investigations. The Vales used a simple structure to represent one bay of the autonomous house and illustrate the principals involved, in this discussion the simple structure is referred to as the 'Vales room'. The basic argument behind the construction of the Vales 'Autonomous' house with high thermal mass is that the high mass allows the heat gains to be captured and become useful heat when required for the space heating. The figure below illustrates the storage capacity of low medium and high loss buildings (U =0.1, 0.2, 0.45 respectively) of thermally light, medium or heavy construction (Thermal Mass = 0.76, 2.55, 16.56 MJ/K respectively) with a ventilation rate of 0.45 ac/h and 70% ventilation heat recovery. This shows that a low loss building of heavy thermal construction at 21 degrees can survive 0 degree external temperatures for 168 hours (1 week) without requiring heating (where 17.5degC is the heating temperature). The simple model can also be easily used to demonstrate that the high mass building has an increased capacity to maintain comfortable temperatures in times of high external temperatures when compared to a low mass equivalent.

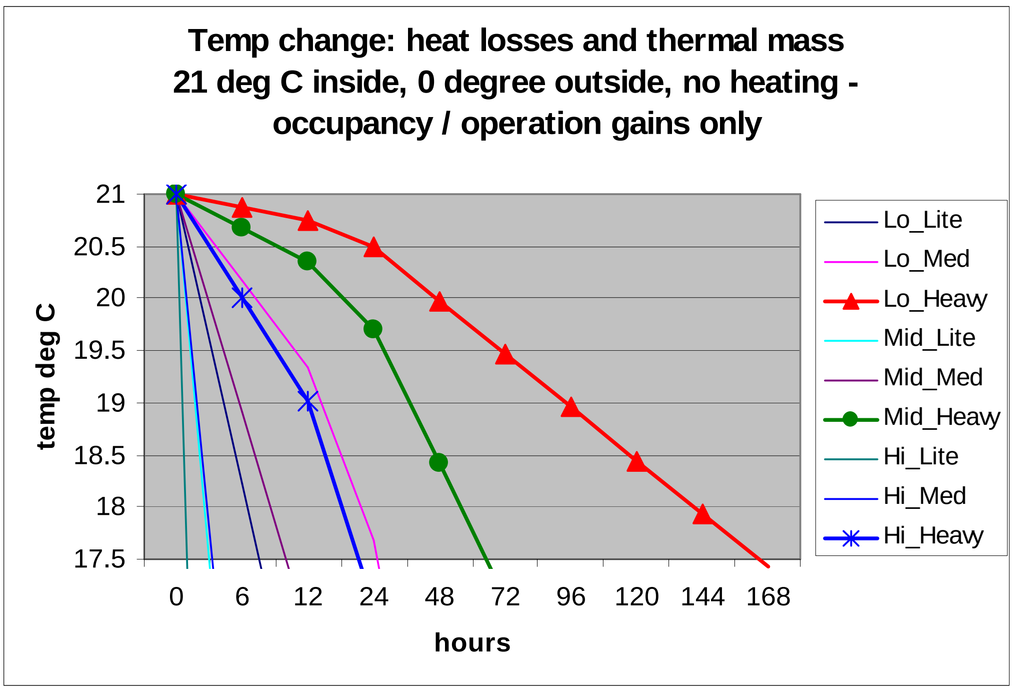
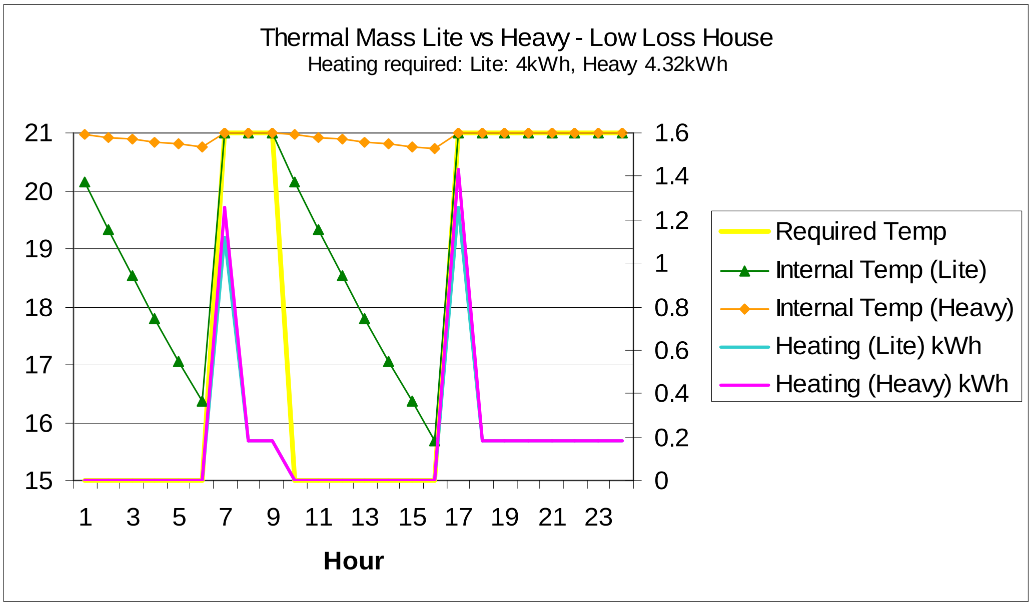



Fig: Thermal storage capacity.

It is postulated that this storage capacity can allow a building to survive cold spells without requiring heating. This assumes that throughout the cold season the gains and ambient temperatures allow the mass to stay sufficiently charged so that heating is not required, this is obviously dependent on insulation, ventilation, occupancy / gains and climate.

The simple model developed from the Vales calculations suggests some further aspects of the operation of thermal mass. The thermal mass acts to moderate swings in temperatures, this moderation is helpful in avoiding overheating or increased ventilation at times of high gains (ventilation cooling is a waste of heat energy!), (note: this aspect of thermal mass makes it highly suitable in climates with high diurnal swings [59]) . The thermal mass can also maintain temperature during low gains periods so that standby heating is not required. Some negative aspects of thermal mass can also be postulated. The gains generated by occupants are highest when the occupants are in residence, in the high mass house the gains may not transfer as directly into increased air temperatures as in a low mass house but will be partially absorbed in the fabric. During periods without occupation the high mass house will maintain a higher temperature than the low mass house and hence loose more heat than a low mass house (driven by the higher temperature difference to the outside temperature) and therefore require more heat to re-charge. The simple model predicts higher heating requirement for high mass construction for a zero degree day with normal occupancy, see graph below.

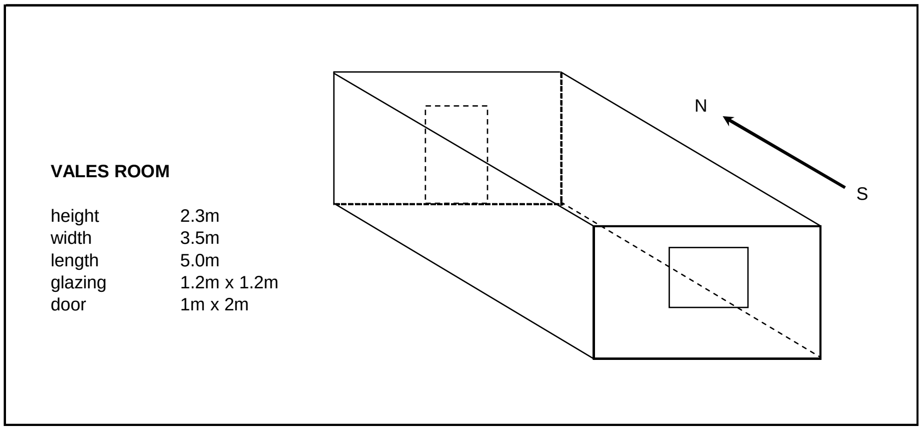



This simple model illustrates some principals of thermal mass but does not allow detailed analysis of realistic heating requirements for comfortable air temperatures in real climates. For this a more sophisticated model is required.

### 5.3 The ESP-r model

ESP-r is a building energy analysis tool developed initially by Joe Clarke of Strathclyde University's Energy Systems Research Unit (ESRU) in the 1980's and developed over 25 years. The basic theory behind the simulator is described in Clarke's book [45] and multiple validation studies are described in the ESRU technical report 'ESP-r: Summary of Validation Studies' [46]. ESP-r has been evaluated as part of the IEA Building energy analysis tool evaluation (BESTEST) [47] and was recently selected after a global survey as the tool of choice to be the basis of the next generation Canadian building energy simulation tool ESP-r/HOT3000 [48]. For this investigation ESP-r is the tool of choice.

In ESP-r the 'Vales room' [8] was recreated using the constructions shown below. The low and high mass constructions are similar to those given in the 'New Autonomous House', in addition a standard mass construction is made up of high mass walls and low mass roof and floor, a very high mass construction was also created by doubling the thickness of the concrete elements in the high mass house.




| Element (thickness in m) | Low Mass | Standard | High Mass | Very High Mass |
|---|---|---|---|---|
| Roof | * insulation<br>.013 plasterboard<br>.003 plaster | * insulation<br>.013 plasterboard<br>.003 plaster | * insulation<br>.150 re-concrete<br>.008 plaster | * insulation<br>.300 re-concrete<br>.008 plaster |
| Walls | * insulation<br>.013 plasterboard<br>.003 plaster | * insulation<br>.100 concrete block<br>.012 plaster | * insulation<br>.100 concrete block<br>.012 plaster | * insulation<br>.200 concrete block<br>.012 plaster |
| Floor | .100 heavy concrete<br>* insulation<br>.0075 softwood<br>.0050 carpet | .100 heavy concrete<br>* insulation<br>.0075 softwood<br>.0050 carpet | * EPS insulation<br>.150 heavy concrete<br>.010 clay tile | * EPS insulation<br>.300 heavy concrete<br>.010 clay tile |

The insulation thicknesses were modified to give appropriate U values per the following table.

| Insulation level | walls | roof | floor | doors | glazing | comment |
|---|---|---|---|---|---|---|
| '0.1' | 0.1 | 0.05 | 0.1 | 0.55 | 0.95 | 'Advanced' * |
| '0.3' | 0.3 | 0.16 | 0.25 | 2 | 2 | '2005 regs.' |
| '0.45' | 0.45 | 0.25 | 0.45 | 2.8 | 3.3 | '1999 regs' |

* these are the actual values from the Vales Autonomous House which are within the UK Advanced and the EU Passive-house values.

The model assumes an ideal heating system, the energy delivered is the amount required to maintain the room dry bulb air temperature at the specified set-point, the heating delivered is 100% convective. The model then allows other temperatures to be monitored e.g. wall surface temperatures, resultant temperature etc.

# Chapter 6:

# ESP-r investigation into the impact of thermal mass, insulation, and ventilation on heating demand across UK climates and occupancies

### 6.1 The heating investigation methodology

In order to simulate the effect of thermal charging and discharging over the summer to winter period simulations were run from 1st July through 30th December.

The 'Vales room' was duplicated and a second room facing north was created to investigate the contribution made by solar gains.

Northern and southern climate files were selected from the ESP-r climate library to represent the range across the UK. Jersey and Copenhagen climate files were selected to represent a spread in UK climates for the heating investigation. A climate summary is given below.

| Climate | lat. | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Copenhagen | 55.6 | 1.5 | 0.2 | 2.9 | 6.2 | 11.5 | 14.7 | 16.6 | 16.9 | 12.3 | 9.7 | 5.1 | 1.6 |
| Dundee | 56.5 | 3.7 | 3.3 | 5.6 | 6.5 | 9.7 | 12.1 | 14.1 | 14.7 | 13.1 | 7.7 | 6 | 5.1 |
| Birmingham | 52.5 | 4.6 | 3.7 | 6.4 | 7.4 | 11 | 14.2 | 17.2 | 16.3 | 13.1 | 9.9 | 6.9 | 5 |
| Jersey | 49.2 | 6.6 | 6.3 | 7.4 | 8.8 | 12 | 14.2 | 16.4 | 17.2 | 15 | 12.9 | 9.4 | 7.3 |

Occupancy based heat demands and gains were established representing realistic scenarios, these are Standard (daily occupancy, average gains) and High (constant use, high gains), Low (daily occupancy, low gains) and Very Low (weekend occupancy only, low gains). The heating controls for each scenario and the casual gains for each scenario in the tables below. The primary source of the gains information is the review in the Vales book chapter 5 [8] and this was cross checked with SAP2001 typical data [32] and found to be in good agreement.

Table: Heat Demand for Scenarios (temperatures in deg C)

| Scenario | 0 - 7 | 7 - 8 | 8 – 9 | 9 - 17 | 17 – 22 | 22 - 24 |
|---|---|---|---|---|---|---|
| Standard | float | 21 | 21 | float | 21 | float |
| High | 17 | 21 | 21 | 21 | 21 | 17 |
| Low | float | 21 | Float | float | 21 | float |
| Very low * | float | 21 | Float | float | 21 | float |

* The Very low heat demand above applies only to weekend days, week-days free float as property is unoccupied. All other heat demands in above table apply to all days of week.

Table: Gains for Standard Scenario

| Gain (W) | 0 – 7 | 7 - 9 | 9 – 17 | 17 - 22 | 22 – 24 |
|---|---|---|---|---|---|
| Occupants | 40 | 60 | 0 | 60 | 40 |
| Lights | 0 | 25 | 0 | 50 | 0 |
| Cook / Appl. | 43 | 125 | 43 | 125 | 43 |
| Hot Water | 10 | 60 | 10 | 60 | 10 |

Table: Gains for High Scenario

| Gain (W) | 0 - 7 | 7 - 9 | 9 - 17 | 17 - 22 | 22 – 24 |
|---|---|---|---|---|---|
| Occupants | 40 | 60 | 45 | 60 | 40 |
| Lights | 0 | 25 | 17 | 50 | 0 |
| Cook / Appl. | 43 | 125 | 116 | 125 | 43 |
| Hot Water | 10 | 60 | 44 | 60 | 10 |

Table: Gains for Low Scenario

| Gain (W) | 0 - 7 | 7 - 9 | 9 - 17 | 17 - 22 | 22 – 24 |
|---|---|---|---|---|---|
| Occupants | 15 | 22 | 0 | 22 | 15 |
| Lights | 0 | 9 | 0 | 18 | 0 |
| Cook / Appl. | 16 | 46 | 16 | 46 | 16 |
| Hot Water | 4 | 22 | 4 | 22 | 4 |

Table: Weekday Gains for Very Low Scenario (Sat /Sun Gains same as for Low Scenario)

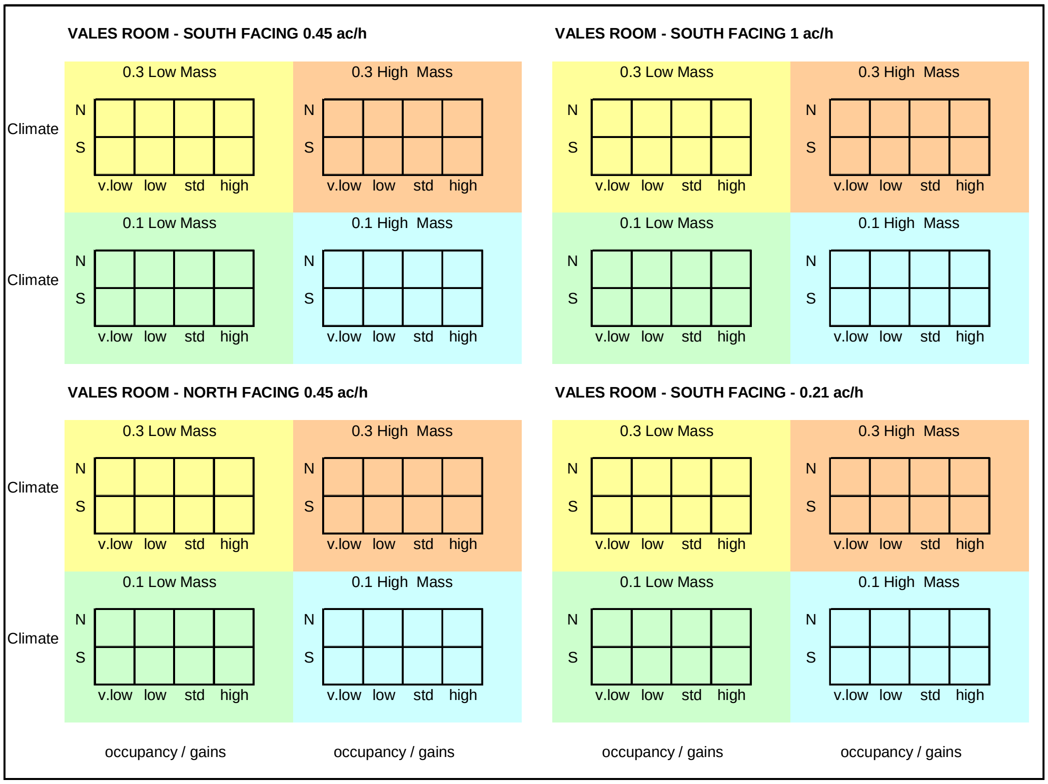
| Gain (W) | 0 - 7 | 7 - 9 | 9 - 17 | 17 - 22 | 22 – 24 |
|---|---|---|---|---|---|
| Weekdays: | | | | | |
| Occupants | 0 | 0 | 0 | 0 | 0 |
| Lights | 0 | 0 | 0 | 9 | 0 |
| Cook / Appl. | 16 | 16 | 16 | 16 | 16 |
| Hot Water | 0 | 0 | 0 | 0 | 0 |

The ventilation rate for the initial investigation was set at 0.45 ac / h and later was varied to 0.21 and 1 ac / h. The 0.45 ac/h ventilation rate was chosen as the normal level for advanced houses [49,8,23] and is also close to the 0.5 ac/h given by SAP2001 for very airtight dwellings naturally ventilated [32]. The 1 ac/h rate was selected to represent an increased ventilation scenario where occupants desire more airflow or to be woken by birds singing, 1 ac/h was in the past a recommended ventilation rate for dwellings. The 0.21 ac/h ventilation rate was chosen as it was used in the Vales calculations to represent the thermal air change rate for a house with MVHR [8].

In all cases the ventilation air source was assumed to be at the ambient outdoor temperature. It should be noted that it is possible to implement a ventilation scheme that sources air from either a sheltered space (e.g. conservatory) or through underground pipe-work [28] which can increase the incoming air temperature and reduce the heating requirement. It would also be possible to implement a ventilation control system which would ventilate based on indoor and outdoor (or conservatory) sensors. These alternates were not investigated as they are not standard practice.

For the heating study to simulate the effect of the use of shading and cross ventilation for avoidance of overheat during warm periods the room was ideally cooled if above 23deg during occupancy and if above 25deg when unoccupied. 23 deg C was chosen based on the ASHRAE Fundamental guidelines chapter 8 [60] which state that winter maximum comfort temperature is at 23.5 deg for a US climate, when the building is unoccupied the temperature is allowed above 23 deg, the 25 deg limit is to represent the leaving of blinds shut and windows open when people are out.

The base experimental plan is given below. For each cell of the matrix an ESP-r simulation with 30min resolution was run over the 6 month period and results file created. Additional investigations were carried out e.g. 1999 regulation buildings (Wall U value = 0.45 W/m2K).


VALES ROOM - SOUTH FACING 0.45 ac/h
VALES ROOM - SOUTH FACING 1 ac/h
VALES ROOM - NORTH FACING 0.45 ac/h
VALES ROOM - SOUTH FACING - 0.21 ac/h
0.3 Low Mass
0.3 High Mass
0.1 Low Mass
0.1 High Mass
Climate
N
S
v.low low std high
occupancy / gains

## 6.2 Heating investigation results

### 6.2.1 Heating, detailed operation

The 2 figures below show examples of the full timeframe plot for low thermal mass Advanced (0.1) and 2005 Regulations (0.3) houses for the standard occupancy / gain scenario and Copenhagen climate. The timeframe for the simulations is from 1st July to 30th December. During the summer period the building is ventilation cooled to 23 degrees during occupancy and 25 degrees if unoccupied, during the heating season the temperature is maintained at 21 degrees when occupied during the daytime.

It can be seen that the heating season starts for the 2005 Regulations (0.3) house on around the 23rd of September while for the Advanced house (0.1) the heating season starts around the 1st of November. The peak heating load for the advanced house is 0.5kW (average over a half hour period) while the peak for the 2005 regulations house is 1.6kW. The advanced house has a minimum temperature of around 15 degrees while the 2005 regulations house has a minimum of around 10 degrees.

Fig: Low thermal mass Advanced standard building with standard occupancy / gains in the Copenhagen climate.

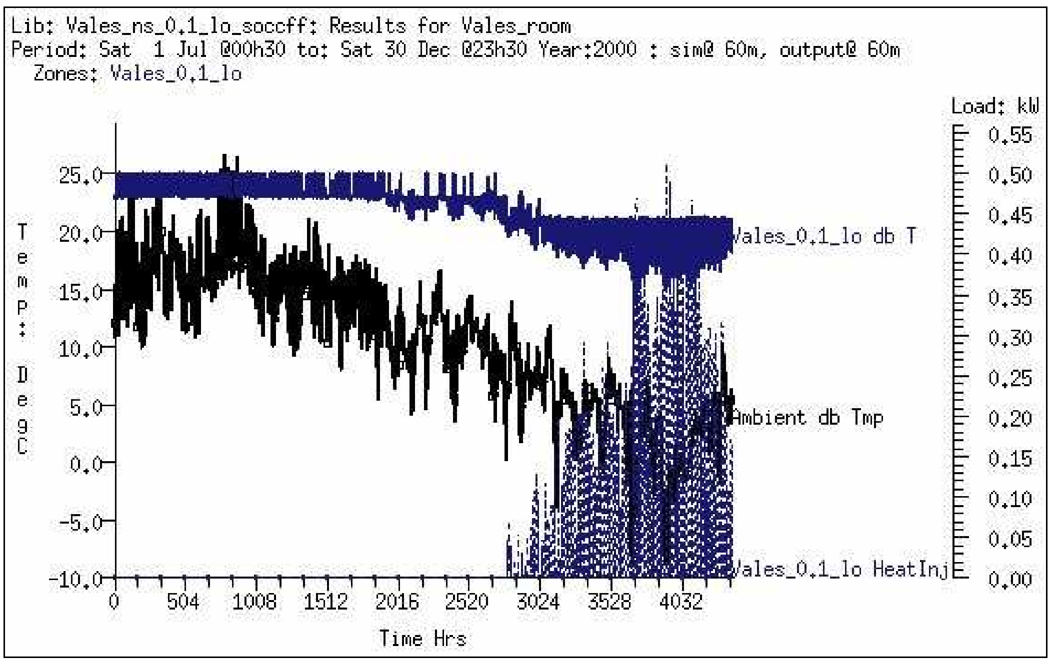
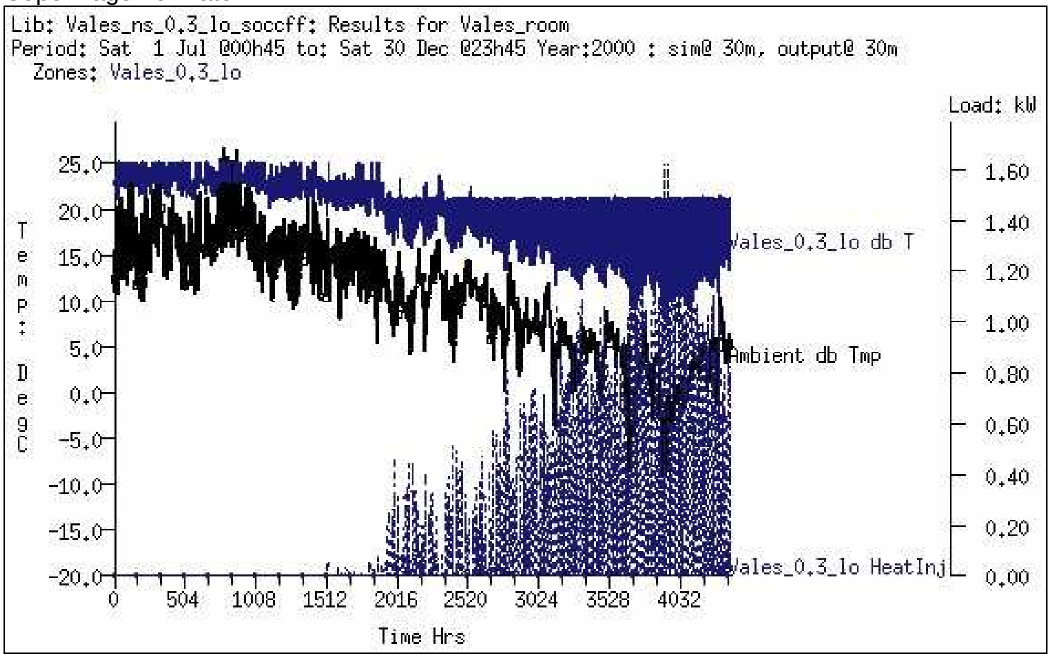


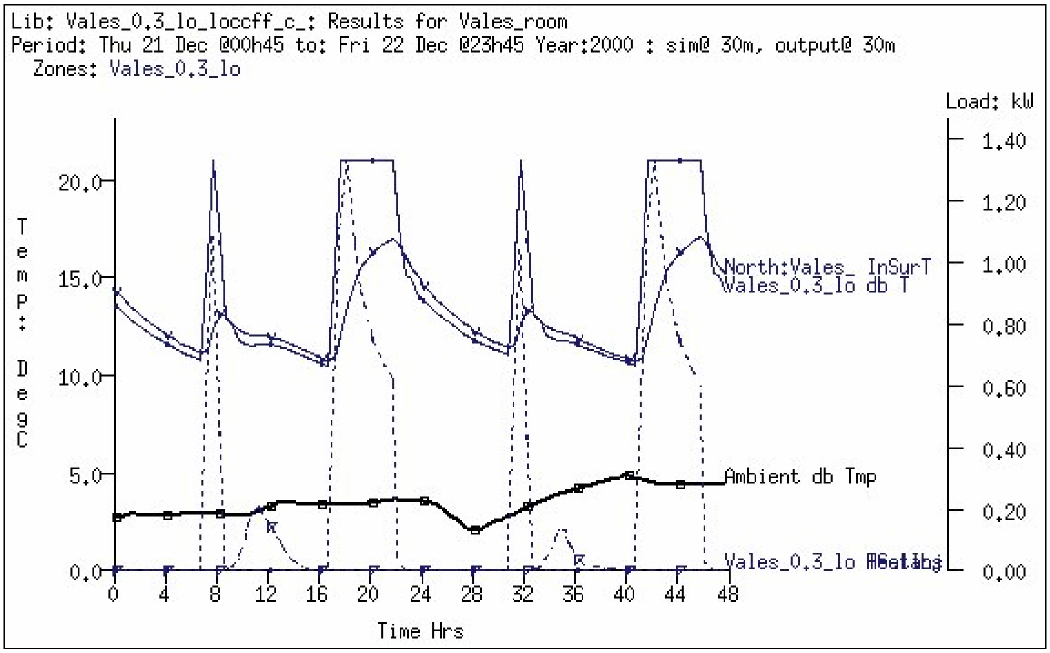
Fig: Low thermal mass 2005 regulations standard building with standard occupancy / gains in the Copenhagen climate.

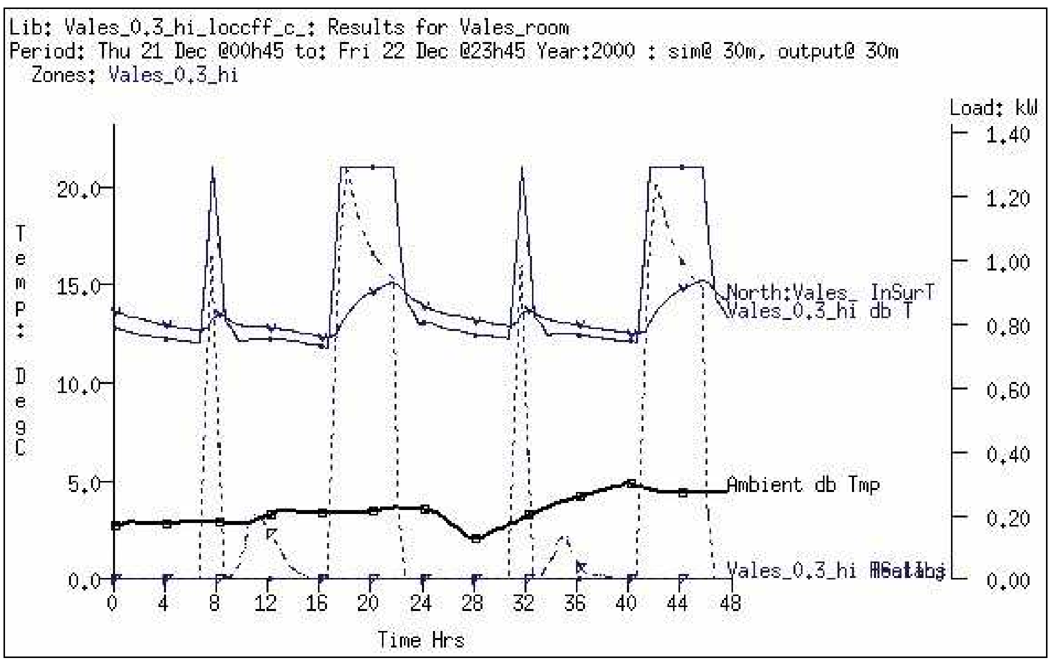



Below are shown graphical examples of the simulated operation of a low thermal mass and a high thermal mass 2005 regulations house with standard occupancy / gains for the 21st and 22nd of December in Copenhagen when the outside temperatures are between 2 and 6 degrees.

The parameters plotted are the inside air dry bulb temperature (Vales_0.3_lo/hi db T), the inside surface of the north wall temperature (North:Vales_ Insur T), the external ambient dry bulb temperature ( Ambient db Tmp), the sensible heating supplied (Vales_0.3_lo/hi Heat Inj) and the solar energy absorbed in the building (Vales_0.3_lo/hi sol-abs).

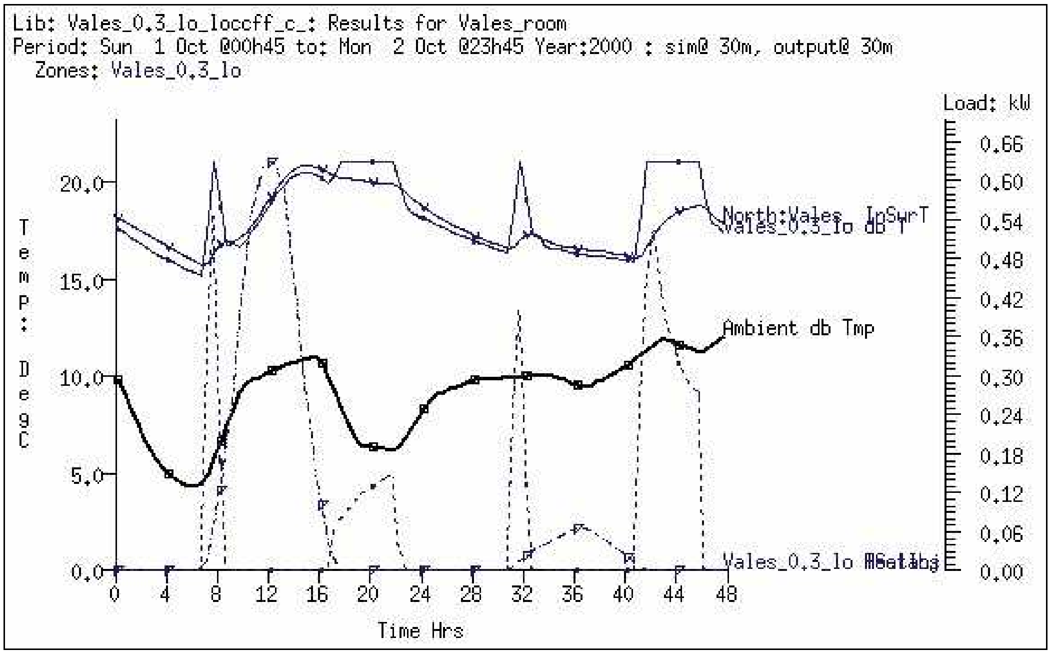
The heating required for the low thermal mass building over this period is 10.8 kWh while the heating required in the high mass house over the same period is 12.2 kWh. In this case the heating is at a higher level for longer in order to maintain the demanded 21 degrees air temperature in the high thermal mass house where the wall surface temperature remains lower (15 degrees peak) than the wall surface temperature in the low thermal mass house (17 degrees peak). The range of maximum to minimum wall surface temperature is 6 degrees in the low thermal mass building compared to 3 degrees in the high thermal mass building while the ranges in the air dry bulb temperatures are closer at 10 degrees and 9 degrees. For both of the days shown the solar gain is very low.

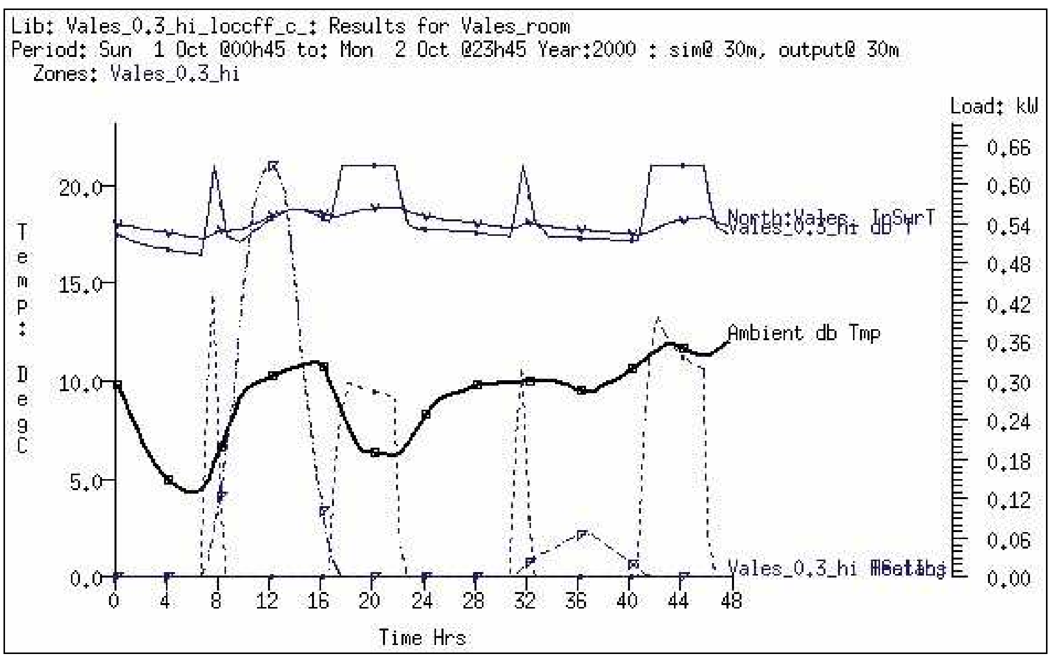



The next 2 graphs below show further examples of the same low and high thermal mass buildings as above but this time for the two day period of the 1st and 2nd October. These two days illustrate a day with high direct solar gain (clear skies) followed by one with only diffuse gain (cloudy).

The high thermal mass house has more variation in the air and wall surface dry bulb temperatures than the low thermal mass house. It is helpful to follow the heating periods over these two days to gain insight into some of the differences between the two constructions. At the first heating period (7-8 hours) the higher difference between the demanded temperature (21deg) and the room temp (15.5deg) in the low mass house leads to a higher heating demand of 0.55kW peak (average over a half hour simulation period) compared to the 0.43kW peak demanded in the high mass house. For the second heating period (16-22 hours) the low thermal mass room air and wall surfaces have been heated to almost the demand temperature by the solar gains and so the low mass house requires less heating than the high mass house where the solar gain resulted in a smaller change in temperature. The third (33-34 hours) and fourth (40-46 hours) heating periods follow a similar pattern to the first with less heating required for the high mass house. Overall the heating required for the low and the high thermal mass buildings for these two days are 3.35 kWh and 3.82 kWh respectively.




The above examples illustrate the various mechanisms which contribute to the heating demands of the buildings and the show the importance of analysing using a complex model and detailed climate data.

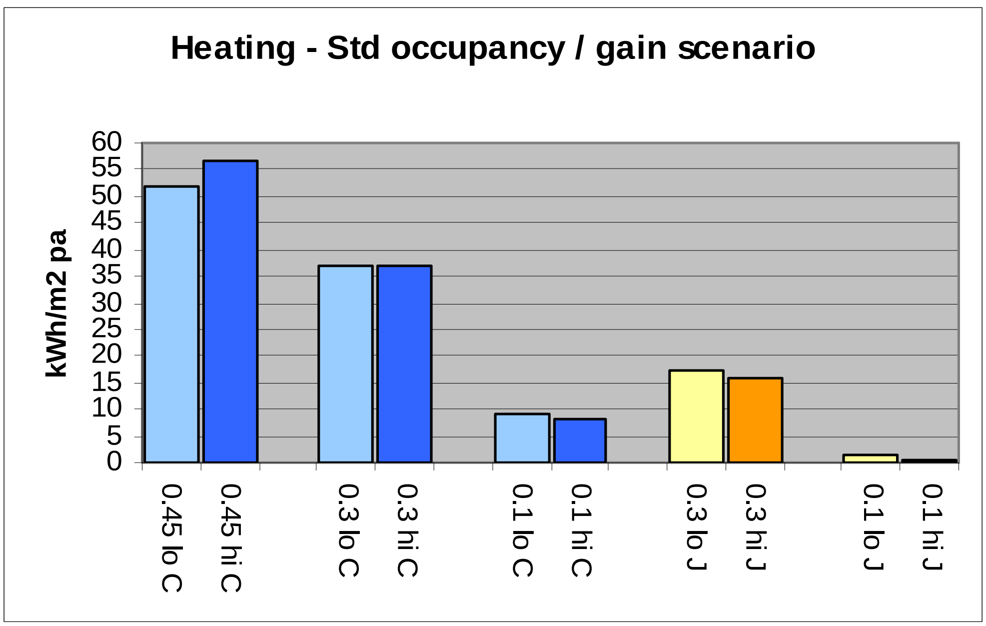
#### 6.2.2 Heating Results: Summary Statistics

In this section the cumulative heating demand in kWh/m2 pa is compared for the different cells of the experimental matrix.

The labels on the graphs follow the convention – insulation level (0.45, 0.3 or 0.1), thermal mass (lo, hi), occupancy / gain scenario (VL – Very Low, L - Low, S - Standard, H - High), climate (C – Copenhagen, J – Jersey), air change rate (.45, .21 or 1).

The cooler colours (light blue, blue) represent low and high thermal mass construction respectively in the northern climate. The warmer colours (yellow, orange) represent low and high thermal mass respectively in the southern climate.

The graph below shows that the 2005 Regulations insulation standard buildings (0.3, lo and hi) require 52-56kWh/m2 pa in the northern climate (Copenhagen, C) and 16-18kWh/m2 pa in the southern climate (Jersey, J). The advanced standard buildings (0.1, lo and hi) require 7-9kWh/m2 pa in the northern climate and 0.5-2kWh/m2 pa in the southern climate. For this scenario the advanced building meets the 'Passive-house' standard (<15kWh/m2 pa heating) across both climate ranges and for both high and low thermal mass constructions.




##### 6.2.2.1 Heating Summary Statistics: Heating requirement v Thermal Mass

(i) Standard Occupancy / Gains Scenario (see graph above)

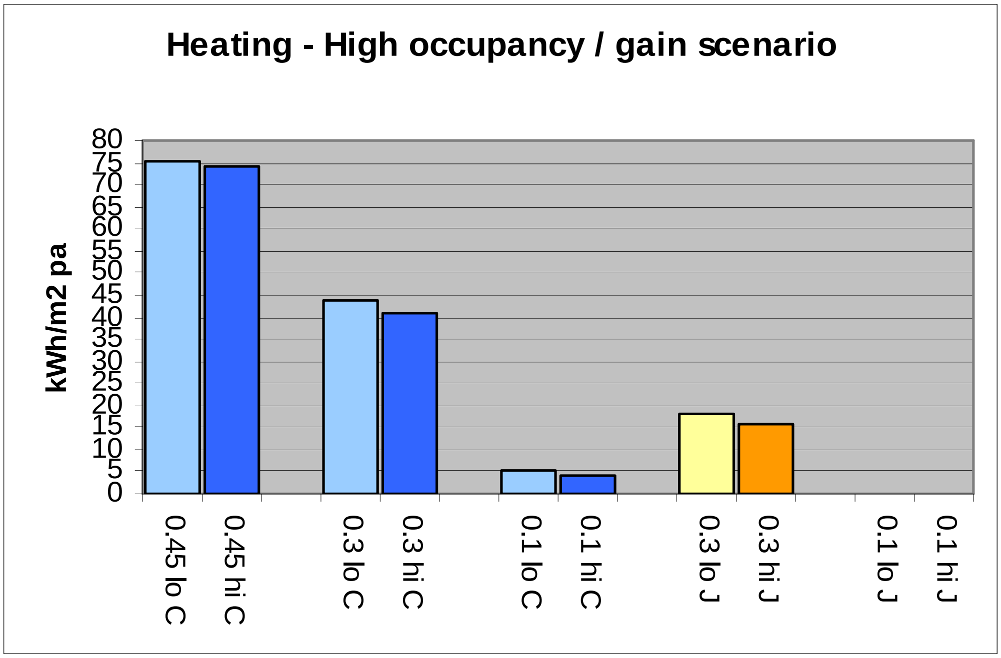
In the northern climate (Copenhagen, C) the high mass construction leads to 10% higher heating than the low mass construction if the building is built to the 1999 Reg's (0.45) but 12% lower heating if the building is to the advanced standard (0.1). Where construction is to the proposed 2005 Reg's (0.3) then the high and low mass constructions have similar heating requirements.

In the southern climate (Jersey, J) the heating demand is reduced in the high thermal mass construction by 8.5% and 60% for buildings constructed to the proposed 2005 Reg's (0.3) and the advanced standard (0.1) respectively.

(ii) High Occupancy / Gains Scenario (graph below)

In the northern climate (Copenhagen, C) the 1999 Regulations construction (0.45) requires the same heating independent of thermal mass however the 2005 Reg's (0.3) and the advanced standard (0.1) show reduction in heating demands for the high mass constructions of 7% and 19% respectively.

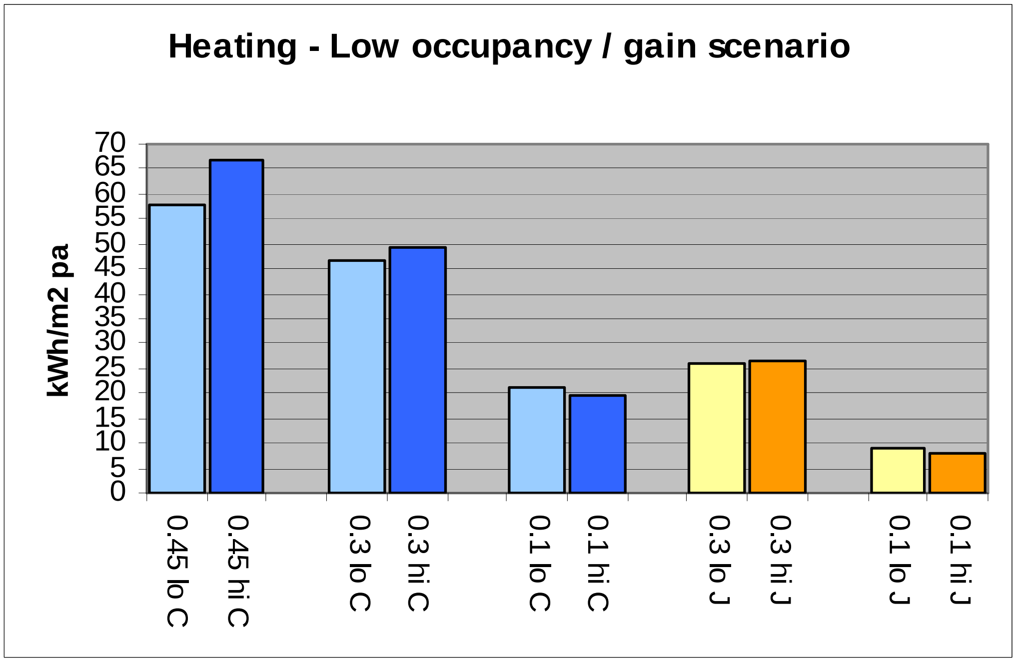
In the southern climate (Jersey, J) the high mass construction again gives reduced heating demands with reductions of 14% and 100% (zero heat required!) for the 2005 (0.3) and the advanced (0.1) constructions respectively.




(iii) Low Occupancy / Gains Scenario (graph below)

In the northern climate (Copenhagen, C) the high mass house requires increased heating compared to the low mass house of 15% and 6.4% if built to the 1999 (0.45) and 2005 (0.3) Reg's respectively. If the house is constructed to the advanced standard (0.1) then the high mass option will require 6% less heating.

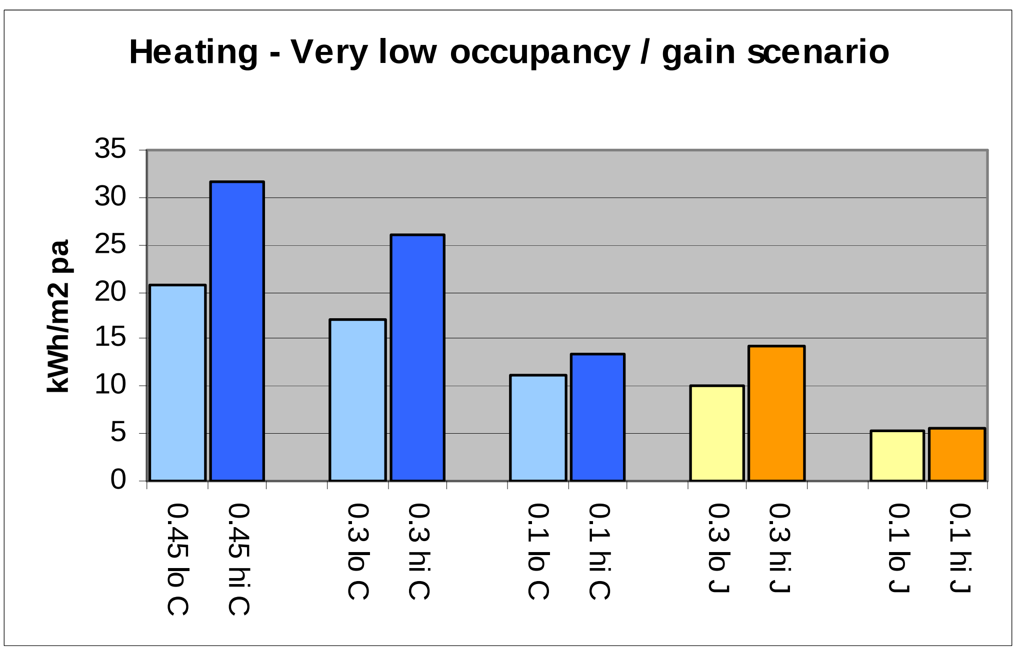
In the southern climate (Jersey, J) the high and low mass houses built to the 2005 Reg's (0.3) have similar heating demands but of the houses built to the advanced standard (0.1) the high mass house requires 14% less heating.




(iv) Very Low Occupancy / Gains Scenario (graph below)

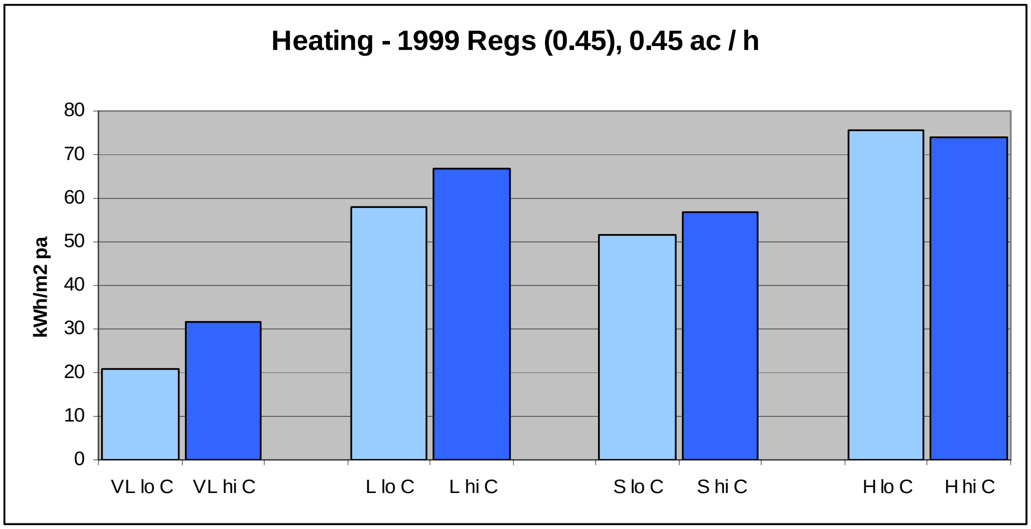
In the northern climate the high mass house requires 52%, 53% and 20% extra heating for the 1999 (0.45), 2005 (0.3) and advanced (0.1) construction standards.

In the southern climate the high mass house built to the 2005 (0.3) regulations requires 41% more heating than the low mass house. In the southern climate in houses built to the advanced standard (0.1) both high and low mass constructions require the same heating.



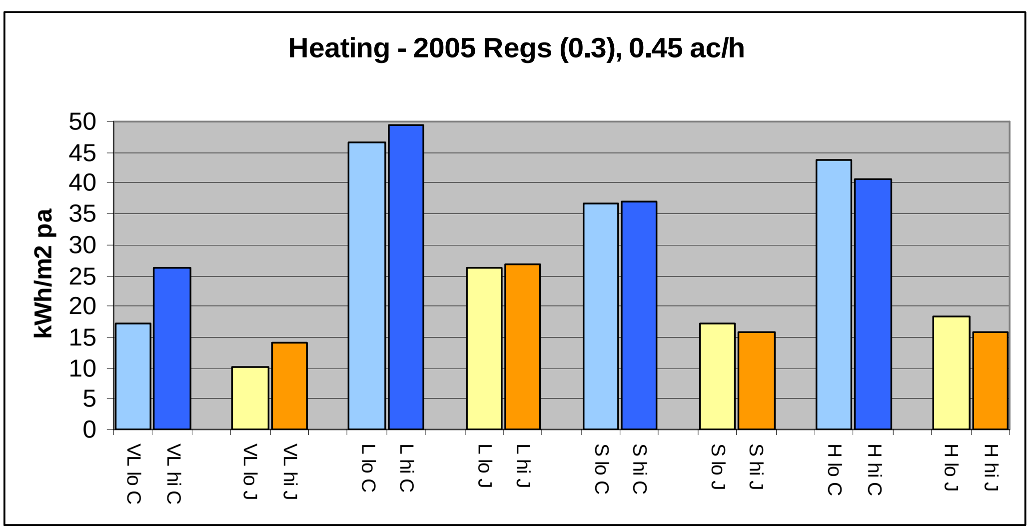
(v) Thermal Mass v. Heating Requirement, reviewed by Construction Standard

Construction to the 1999 standard (0.45) was investigated for the northern climate (Copenhagen, C) across the occupancy / gain scenarios (graph below). The high mass house heating demand was found to be 52%, 15% and 10% higher than the low mass equivalent for the very low, low and standard occupancy / gain scenarios respectively. The high and low mass houses had similar heating demands for the high occupancy / gains scenario.

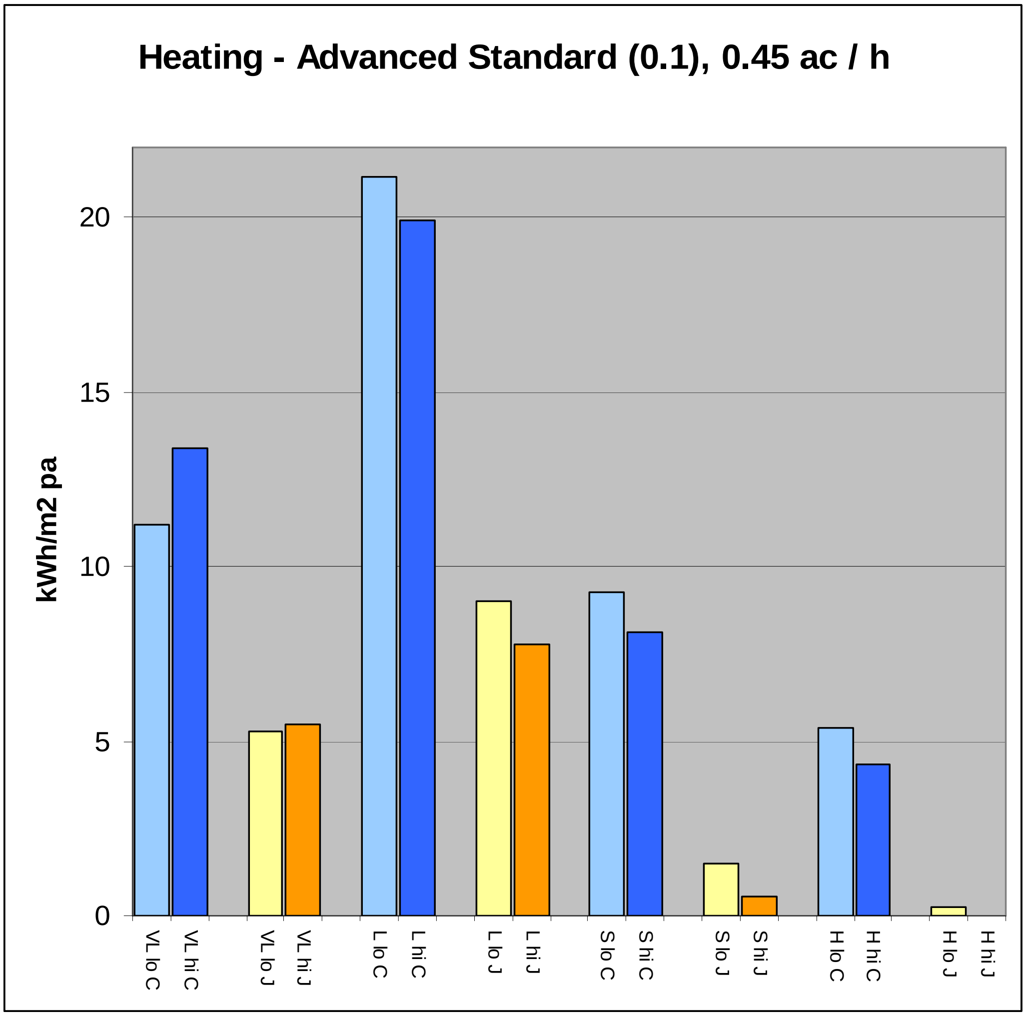



For houses built to the proposed 2005 Reg's (0.3) (graphbelow) in the northern climate, the very low and low occupancy / gain scenarios showed the high mass house requiring 53% and 6.4% extra heating respectively. The standard occupancy / gains scenario showed the high and low mass houses to have similar demands and the high occupancy / gains scenario showed the high mass house to have a reduction of 7% in heating demand.

For houses built to the proposed 2005 Reg's (0.3) (graph below) in the southern climate, the very low occupancy showed the high mass house to require 41% more heating but the low occupancy gain scenario showed no difference between the low and high mass buildings, the standard and high occupancy / gain scenarios showed the high mass building to demand 8.5% and 14% less heating respectively.



For construction to the advanced standard (0.1) (graph below) only the very low occupancy / gain scenario in the northern climate showed the high mass construction to perform worse than the low mass, in this case requiring 20% more heating. The same occupancy / gain scenario in the southern climate gave similar heating for both high and low mass buildings. The low standard and high occupancies in the northern climate gave 6%, 12% and 19% reductions and in the southern climate gave 14%, 60% and 100% reductions compared to the low mass equivalents.




(vi) Summary of Impact of thermal mass on heating demands

The table below summarises the impact of thermal mass on heating demands for climates and occupancy / gain scenarios chosen to represent variation across the UK. The percentages represent the difference in heating requirement between thermally low and high mass constructions as a percentage of the heating required by the low mass house i.e. [{Heat(hi) – Heat(lo)}/Heat(lo)]*100%.

| Building Standard | Climate | Vent | Demand / Gain Scenario | | | |
|---|---|---|---|---|---|---|
| | | | V low | Low | Std | High |
| 1999 Regulations (0.45) | North | 0.45 | 52% | 15% | 10% | - |
| 2005 Regulations (0.3) | North | 0.45 | 53% | 6% | - | -7% |
| UK Advanced (0.1) | North | 0.45 | 20% | -6% | -12% | -19% |
| 2005 Regulations (0.3) | South | 0.45 | 41% | - | -8% | -14% |
| UK Advanced (0.1) | South | 0.45 | - | -14% | -60% | -100% |

Where less than 5% difference was seen between the different constructions then the result is shown in the above table as ‘ - ‘.

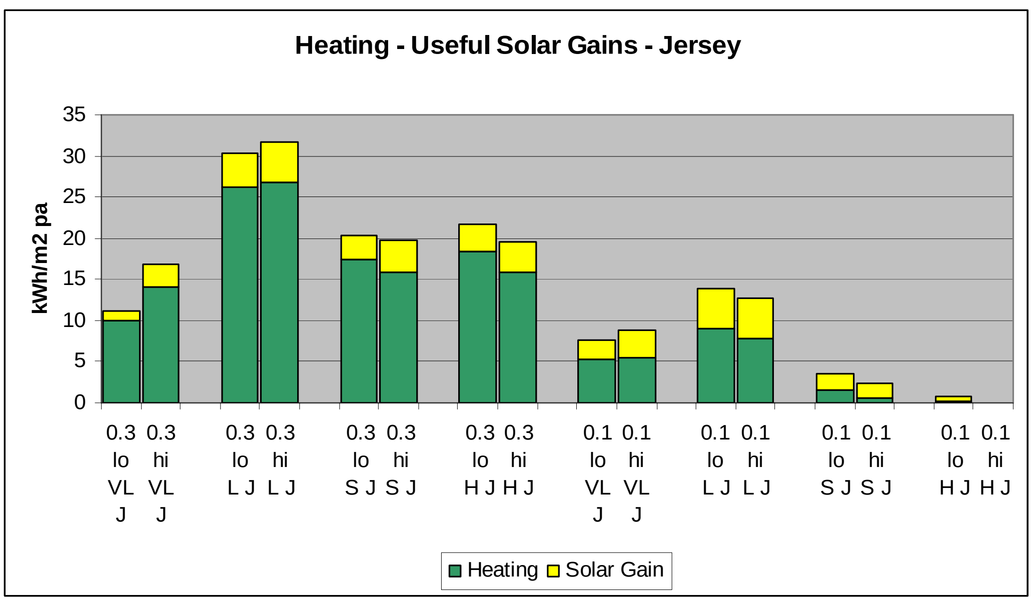
For advanced construction standard the high thermal mass construction gives significant reduction in heating with the exception of the very low occupancy / gain (weekend use only, low gains) in northern climate case.

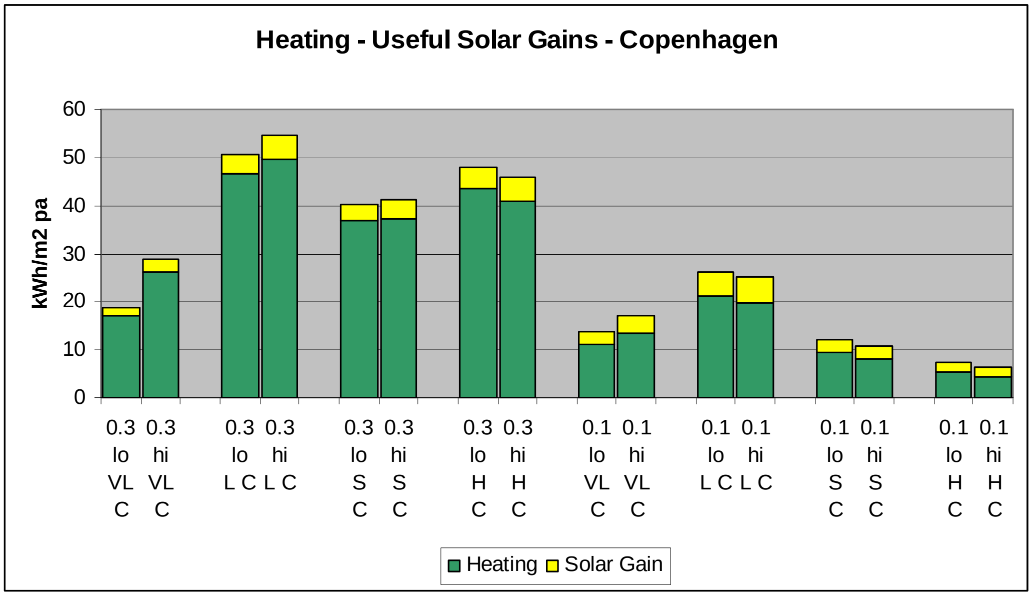
For 2005 building regulations the high mass construction is favourable in the southern climate with the exception of the very low occupancy / gain scenario (weekend use only). In the northern climate the high mass is favourable with higher occupancy / gain scenarios but low mass performs best in lower occupancy / gain scenarios.

Poorer construction standards make high mass construction less favourable. The 1999 regulations case in the northern climate shows increased heating required for the high thermal mass construction for very low, low and standard occupancy / gain scenarios.

#### 6.2.2.2 Heating Summary Statistics, Useful Solar Gains

To gain insight into the useful solar gains through the south facing window the heating requirements of the Vales Room were compared to an identical room rotated 180 degrees so that the window faced north. The higher heating demand of the north facing room was postulated to be equivalent to the heating due to the direct solar gain captured through the south facing window. The two graphs below show the results of this analysis. The ‘heating’ bar represents the heating required in the south facing room, the ‘solar gain’ element is the difference between the north facing and south facing heat demand, the full bar height then represents the heating demand of the north facing room.






It can be seen that the high mass house has in general an increase in useful solar gain although the difference between high and low mass houses is small compared to the total heating required especially for the northern climate.

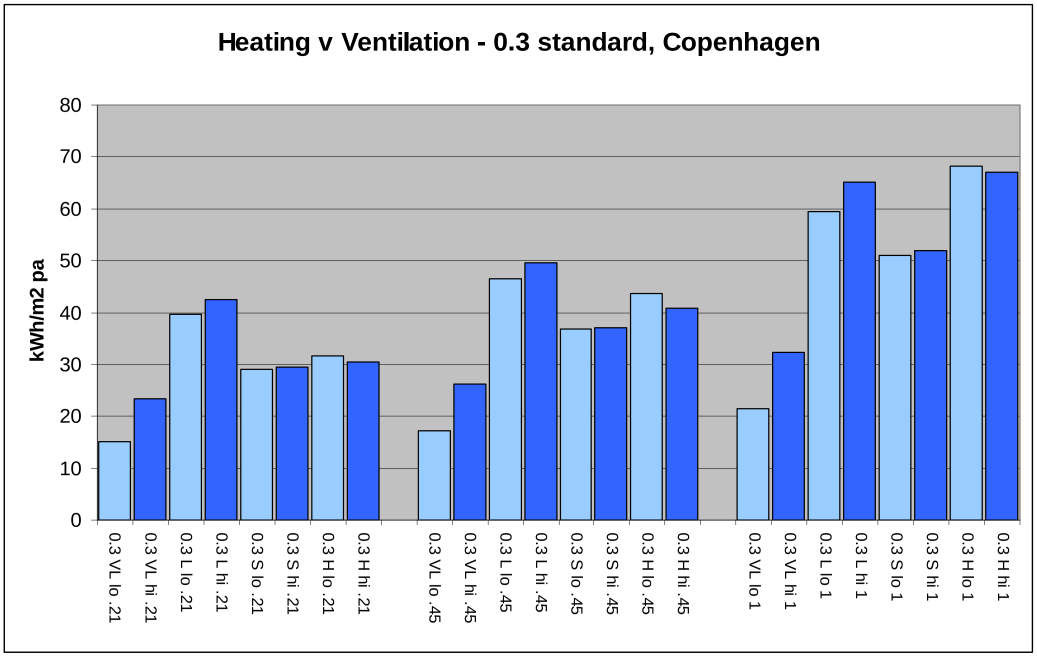
#### 6.2.2.3 Heating Summary Statistics: Ventilation

As discussed in the section on the methodology, the ventilation rates investigated are; 0.45 ac/h representing the standard rate in advanced housing, 1 ac/h representing occupants who demand increased ventilation and 0.21 ac/h representing the thermal air change rate where MVHR is installed.

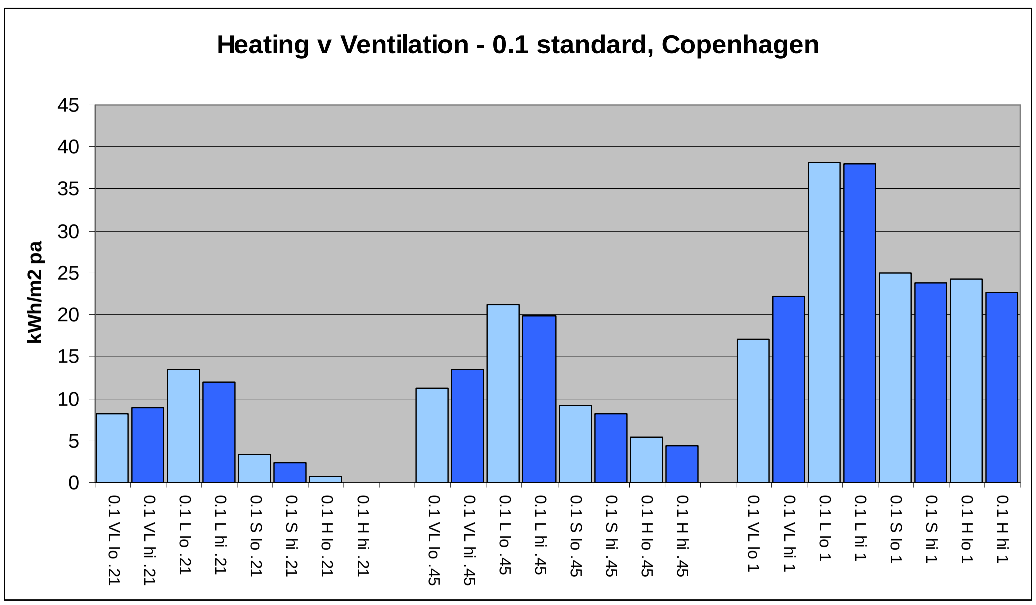
The results are shown in graphs below. It can be seen that the ventilation rate has a large impact on heating demand with the relative effect being highest at advanced insulation standards (0.1) for the higher occupancy / gain scenarios (S, H).

For the northern climate only the advanced (0.1) insulation standard in combination with the 0.21 ac/h ventilation rate meets the Passive-house criteria of < 15 kWH/m2 pa heating across all occupancy / gain scenarios which is consistent with the inclusion of MVHR in this standard.

It is worth stating again that all ventilation is assumed to be from ambient external air, some reduction in heating requirement would be gained if ground air pipes [28] or conservatory ventilation schemes were successfully implemented.



Heating v Ventilation - 0.3 standard, Copenhagen
kWh/m2 pa
80
70
60
50
40
30
20
10
0
0.3 VL lo .21
0.3 VL hi .21
0.3 L lo .21
0.3 L hi .21
0.3 S lo .21
0.3 S hi .21
0.3 H lo .21
0.3 H hi .21
0.3 VL lo .45
0.3 VL hi .45
0.3 L lo .45
0.3 L hi .45
0.3 S lo .45
0.3 S hi .45
0.3 H lo .45
0.3 H hi .45
0.3 VL lo 1
0.3 VL hi 1
0.3 L lo 1
0.3 L hi 1
0.3 S lo 1
0.3 S hi 1
0.3 H lo 1
0.3 H hi 1

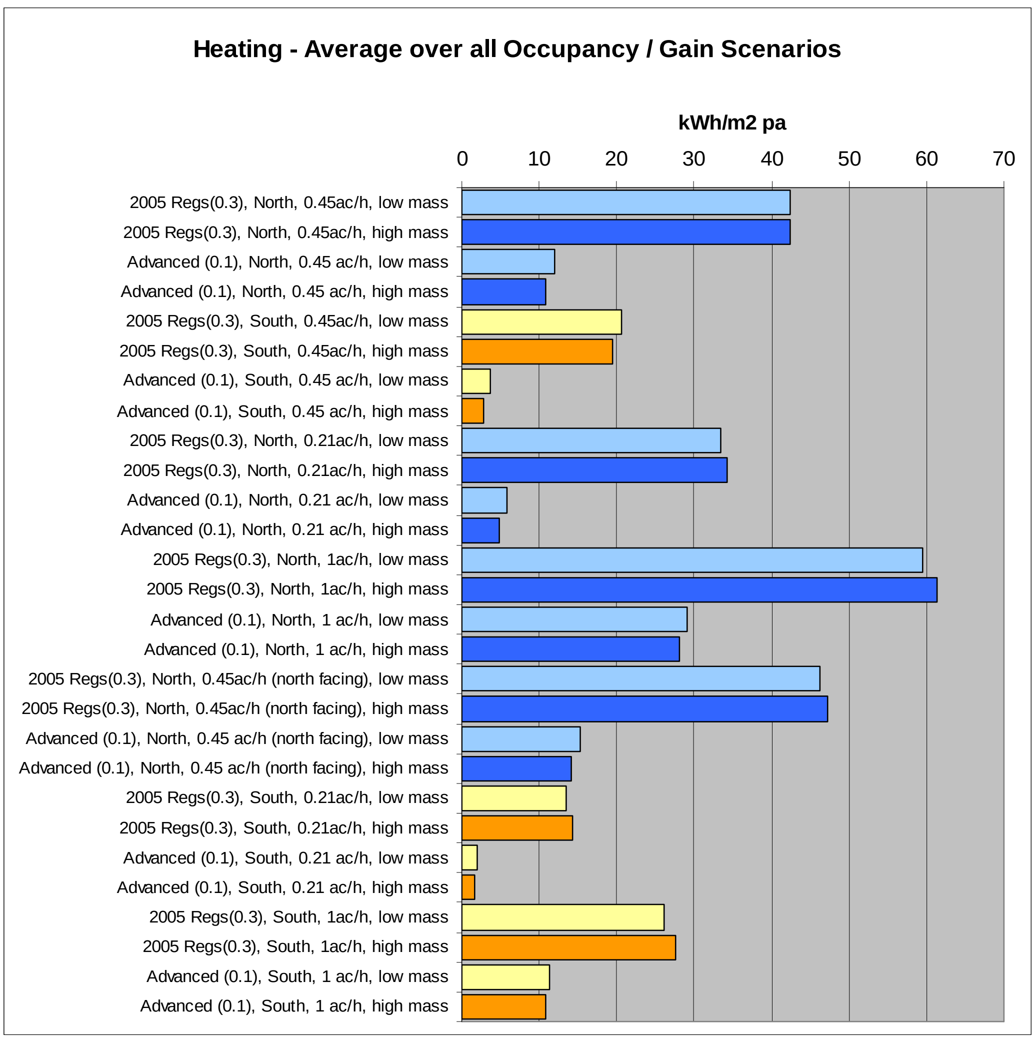



Heating v Ventilation - 0.1 standard, Copenhagen
kWh/m2 pa
45
40
35
30
25
20
15
10
5
0
0.1 VL lo .21
0.1 VL hi .21
0.1 L lo .21
0.1 L hi .21
0.1 S lo .21
0.1 S hi .21
0.1 H lo .21
0.1 H hi .21
0.1 VL lo .45
0.1 VL hi .45
0.1 L lo .45
0.1 L hi .45
0.1 S lo .45
0.1 S hi .45
0.1 H lo .45
0.1 H hi .45
0.1 VL lo 1
0.1 VL hi 1
0.1 L lo 1
0.1 L hi 1
0.1 S lo 1
0.1 S hi 1
0.1 H lo 1
0.1 H hi 1

### 6.2.3 Heating Summary Statistics: Relative impact on Heating of solar gain, thermal mass, ventilation, climate and insulation.

The summary table and graph below show the heating requirements for each of the building standard / climate / ventilation combinations averaged across the 4 occupancy / gain scenarios. Based on this average data, insulation standard, ventilation, climate and orientation have much larger effects than thermal mass on the heating requirements.

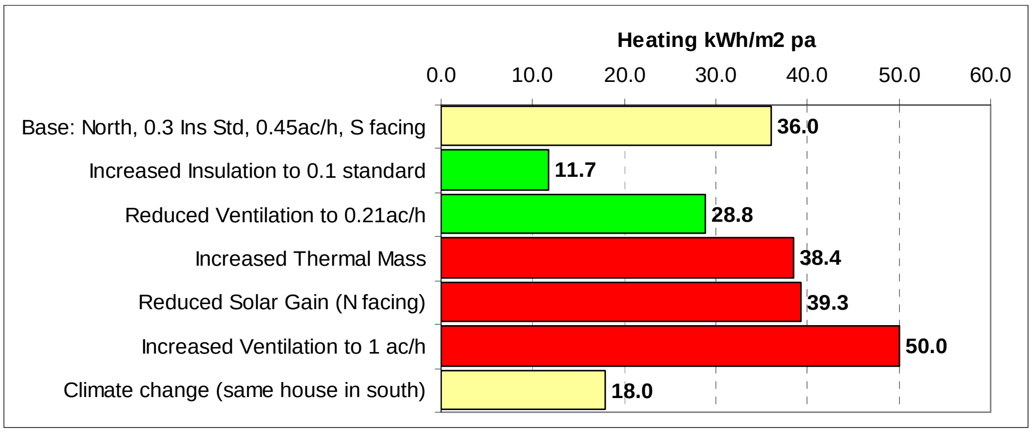
| Building Standard | Climate | Vent | Heating kWh/m2 pa Demand / Gain Scenario: Very Low Mass | | Low Mass | | Standard Mass | | High Mass | | Avg | Avg low mass | Avg high mass |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | low | high | low | high | low | high | low | high | | | |
| 2005 Regulations ( 0.3 ) | North | 0.45 | 17.1 | 26.2 | 46.5 | 49.5 | 36.8 | 37.1 | 43.7 | 40.8 | 37.2 | 36.0 | 38.4 |
| UK Advanced ( 0.1 ) | North | 0.45 | 11.2 | 13.4 | 21.1 | 19.9 | 9.3 | 8.1 | 5.4 | 4.3 | 11.6 | 11.7 | 11.4 |
| 2005 Regulations ( 0.3 ) | South | 0.45 | 10.1 | 14.2 | 26.2 | 26.7 | 17.4 | 15.9 | 18.3 | 15.8 | 18.1 | 18.0 | 18.1 |
| UK Advanced ( 0.1 ) | South | 0.45 | 5.3 | 5.5 | 9.0 | 7.8 | 1.5 | 0.6 | 0.2 | 0.0 | 3.7 | 4.0 | 3.5 |
| 2005 Regulations ( 0.3 ) | North | 0.21 | 15.1 | 23.3 | 39.5 | 42.4 | 29.0 | 29.6 | 31.7 | 30.5 | 30.1 | 28.8 | 31.5 |
| UK Advanced ( 0.1 ) | North | 0.21 | 8.1 | 8.9 | 13.4 | 12.0 | 3.3 | 2.4 | 0.7 | 0.0 | 6.1 | 6.4 | 5.8 |
| 2005 Regulations ( 0.3 ) | North | 1 | 21.5 | 32.2 | 59.5 | 65.1 | 51.0 | 52.0 | 68.1 | 67.1 | 52.1 | 50.0 | 54.1 |
| UK Advanced ( 0.1 ) | North | 1 | 17.0 | 22.2 | 38.2 | 37.9 | 25.0 | 23.9 | 24.2 | 22.6 | 26.4 | 26.1 | 26.7 |
| 2005 Regs ( 0.3 ) N facing | North | 0.45 | 18.7 | 28.9 | 50.6 | 54.5 | 40.1 | 41.4 | 47.8 | 45.9 | 41.0 | 39.3 | 42.7 |
| UK Advanced ( 0.1 ) N facing | North | 0.45 | 13.8 | 17.1 | 26.3 | 25.3 | 12.0 | 10.9 | 7.4 | 6.5 | 14.9 | 14.9 | 14.9 |
| 2005 Regulations ( 0.3 ) | South | 0.21 | 8.6 | 12.3 | 21.1 | 22.2 | 12.5 | 11.8 | 11.7 | 10.6 | 13.8 | 13.5 | 14.2 |
| UK Advanced ( 0.1 ) | South | 0.21 | 3.3 | 3.0 | 4.8 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 1.8 | 2.0 | 1.7 |
| 2005 Regs ( 0.3 ) N facing | South | 1 | 12.7 | 18.2 | 34.4 | 36.8 | 25.7 | 26.1 | 31.5 | 29.4 | 26.8 | 26.1 | 27.6 |
| UK Advanced ( 0.1 ) N facing | South | 1 | 9.1 | 10.9 | 19.4 | 18.4 | 9.4 | 8.1 | 7.1 | 5.7 | 11.0 | 11.2 | 10.8 |



#### 6.2.3.1 Heating relative to the north climate, 2005 regs, 0.45 ac/h, south facing base case:

The table and graph below look at the variation in heating demand relative to the north climate, 2005 building regulations (0.3), 0.45 ac/h, south facing case. The relative impact of the factors are (in descending order of impact); insulation standard (-67%), climate (-50%), ventilation (-20%, +39%), orientation (+9%) and thermal mass (+7%).

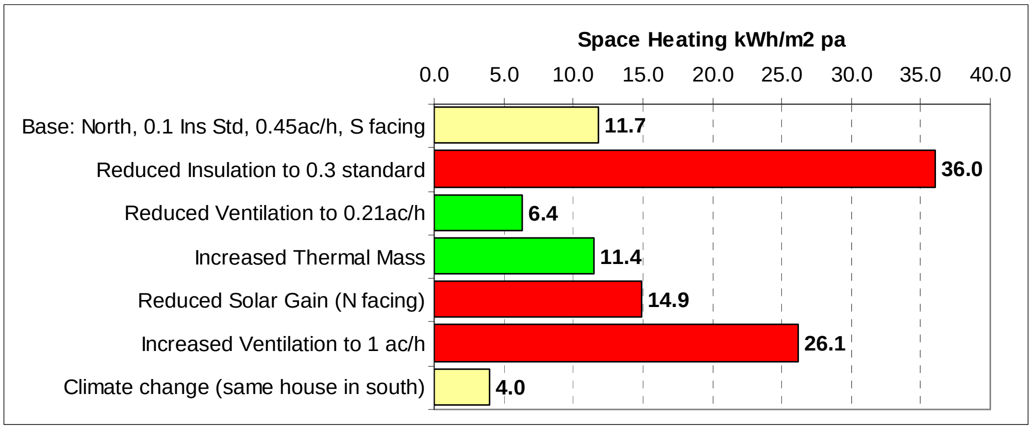
| | | | | | | Heating kWh/m2 pa | | |
|---|---|---|---|---|---|---|---|---|
| | Reg's | Mass | Climate | Vent | Glaz | Avg | Delta | % |
| Base Scenario Average Heating | 0.3 | low | north | 0.45 | south | 36.0 | | |
| Increased Insulation to 0.1 standard | 0.1 | low | north | 0.45 | south | 11.7 | -24.3 | -67 |
| Reduced Ventilation Losses to 0.21ac/h | 0.3 | low | north | 0.21 | south | 28.8 | -7.2 | -20 |
| Increased Thermal Mass | 0.3 | high | north | 0.45 | south | 38.4 | 2.4 | 7 |
| Reduced Solar Gain (N facing) | 0.3 | low | north | 0.45 | north | 39.3 | 3.3 | 9 |
| Increased Ventilation to 1 ac/h | 0.3 | low | north | 1 | south | 50.0 | 14.0 | 39 |
| Climate change (same house in south) | 0.3 | low | south | 0.45 | south | 18.0 | -18.1 | -50 |




#### 6.2.3.2 Heating relative to the north climate, Advanced regs, 0.45 ac/h, south facing base case:

The table and graph below look at the variation in heating demand relative to the north climate, advanced insulation standards (0.1), 0.45 ac/h, south facing case. The relative impact of the factors are (in descending order of impact); insulation standard (+207%), climate (-66%), ventilation (-46%, +122%), orientation (+27%) and thermal mass (-3%).

| | | | | | | Heating kWh/m2 pa | | |
|---|---|---|---|---|---|---|---|---|
| | Reg's | Mass | Climate | Vent | Glaz | Avg | Delta | % |
| Base Scenario Average Heating | 0.3 | low | north | 0.45 | south | 11.7 | | |
| Reduced Insulation to 0.3 standard | 0.1 | low | north | 0.45 | south | 36.0 | 24.3 | 207 |
| Reduced Ventilation Losses to 0.21ac/h | 0.3 | low | north | 0.21 | south | 6.4 | -5.4 | -46 |
| Increased Thermal Mass | 0.3 | high | north | 0.45 | south | 11.4 | -0.3 | -3 |
| Reduced Solar Gain (N facing) | 0.3 | low | north | 0.45 | north | 14.9 | 3.1 | 27 |
| Increased Ventilation to 1 ac/h | 0.3 | low | north | 1 | south | 26.1 | 14.4 | 122 |
| Climate change (same house in south) | 0.3 | low | south | 0.45 | south | 4.0 | -7.7 | -66 |

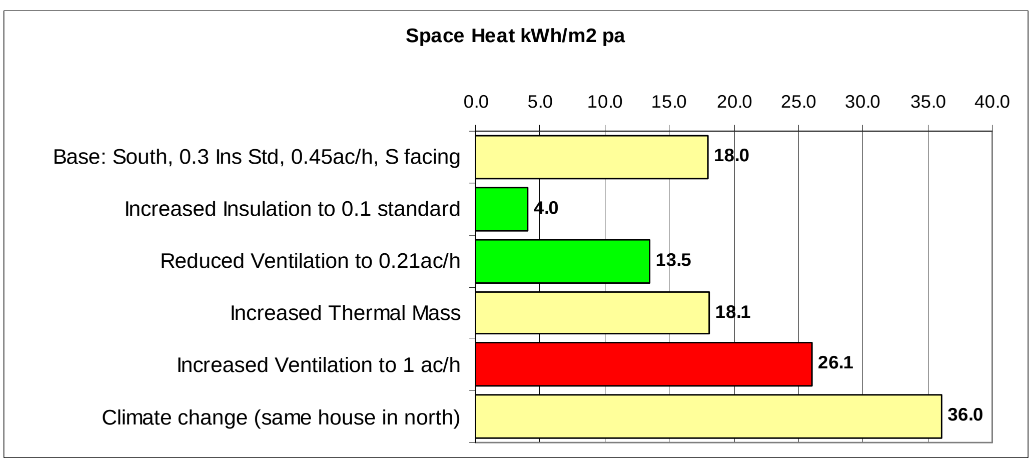



The effects of insulation, ventilation and orientation are relatively larger against the lower base of the 0.1 insulation case.

#### 6.2.3.3 Heating relative to the south climate, 2005 regs, 0.45 ac/h, south facing base case:

The table and graph below look at the variation in heating demand relative to the south climate, proposed 2005 reg's standards (0.3), 0.45 ac/h, south facing case. The relative impact of the factors are (in descending order of impact); insulation standard (-78%), climate (+100%), ventilation (-25%, +45%), orientation and thermal mass (+1%).

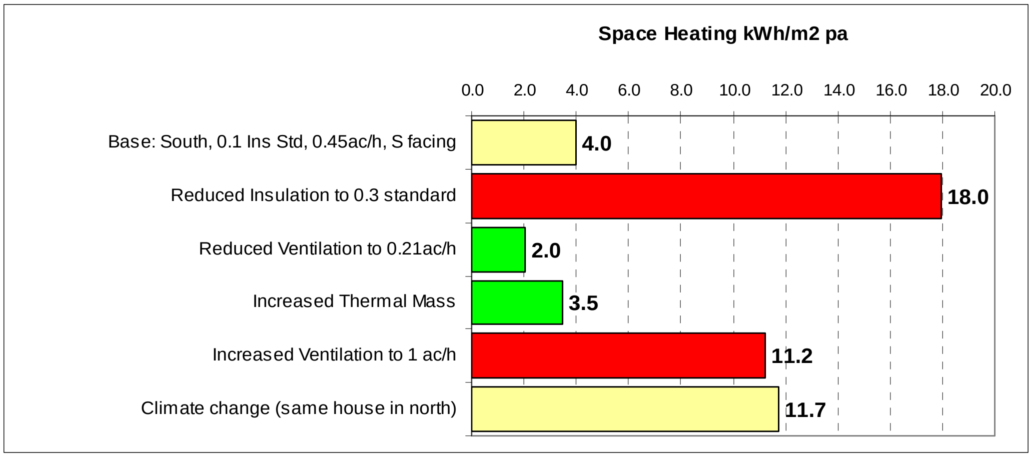
| | | | | | | Heating kWh/m2 pa | | |
|---|---|---|---|---|---|---|---|---|
| | Reg's | Mass | Climate | Vent | Glaz | Avg | Delta | % |
| Base Scenario Average Heating | 0.3 | low | south | 0.45 | south | 18.0 | | |
| Increased Insulation to 0.1 standard | 0.1 | low | south | 0.45 | south | 4.0 | -14.0 | -78 |
| Reduced Ventilation to 0.21ac/h | 0.3 | low | south | 0.21 | south | 13.5 | -4.5 | -25 |
| Increased Thermal Mass | 0.3 | high | south | 0.45 | south | 18.1 | 0.2 | 1 |
| Increased Ventilation to 1 ac/h | 0.3 | low | south | 1 | south | 26.1 | 8.1 | 45 |
| Climate change (same house in north) | 0.3 | low | south | 0.45 | south | 36.0 | 18.1 | 100 |




#### 6.2.3.4 Heating relative to the south climate, Advanced regs, 0.45 ac/h, south facing base case:

The table and graph that follow look at the variation in heating demand relative to the south climate, advanced insulation standards (0.1), 0.45 ac/h, south facing case. The relative impact of the factors are (in descending order of impact); climate (-194%), insulation standard (+349%), ventilation (-49%, +181%) and thermal mass (-14%).

| | Reg's | Mass | Climate | Vent | Glaz | Heating kWh/m2 pa | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Avg | Delta | % |
| Base Scenario Average Heating | 0.3 | low | south | 0.45 | south | 4.0 | | |
| Reduced Insulation to 0.3 standard | 0.1 | low | south | 0.45 | south | 18.0 | 14.0 | 349 |
| Reduced Ventilation Losses to 0.21ac/h | 0.3 | low | south | 0.21 | south | 2.0 | -2.0 | -49 |
| Increased Thermal Mass | 0.3 | high | south | 0.45 | south | 3.5 | -0.5 | -14 |
| Increased Ventilation to 1 ac/h | 0.3 | low | south | 1 | south | 11.2 | 7.2 | 181 |
| Climate change (same house in north) | 0.3 | low | south | 0.45 | south | 11.7 | 7.7 | 194 |




For all cases when considering the average data then insulation, climate, ventilation and orientation have larger impacts on heating than thermal mass.

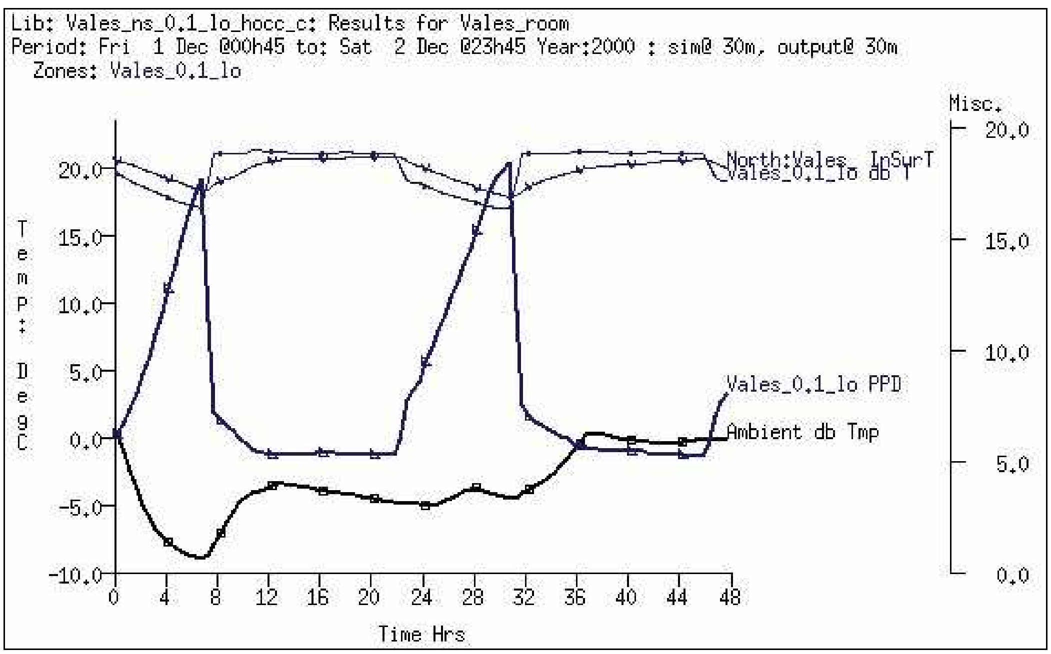
#### 6.2.4 Heating Results – Thermal Comfort

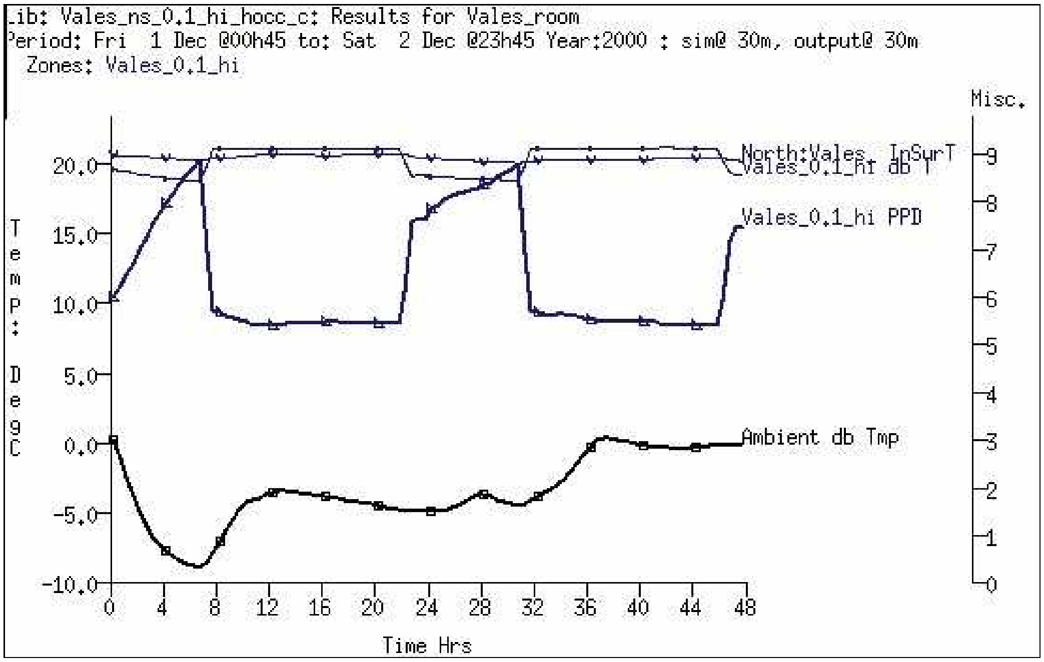
Throughout the heating evaluation the results were reviewed for thermal comfort of occupants. The ESP-r software has embedded the Percent Mean Vote (PMV) and Percent of Persons Dissatisfied (PPD) metrics which are documented in the ASHRAE Fundamentals Chapter 8 'Thermal Comfort' [60] and are used as a standard. For this evaluation the clothing level was set ant 0.7 Clo to represent normal winter indoor clothing (no jumper) and the occupant activity level was set at 1.5 MET (or 87W) to represent a mix of sedentary and light activities.

The PPD results for some of the scenario's are shown in figures 9 – 9 below. The values that are deemed acceptable when the house is occupied and the occupants are awake is defined in the PMV-PPD method as within +/- 5 PMV (or <= 10% PPD) for perfect comfort and within +/- 1 PMV (or <= 26% PPD) for a slight discomfort but acceptable comfort level.

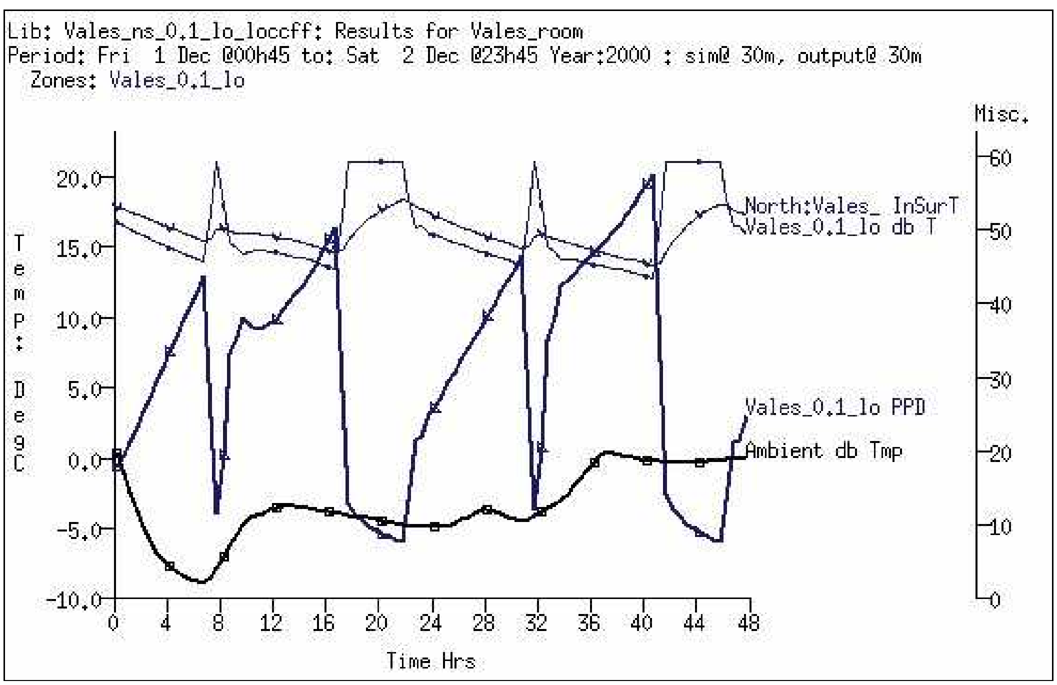
The first two graphs below show the air dry bulb temperature, the wall surface temperature, the outside ambient temperature and the PPD metric ('Misc.' scale) for the coldest day and the following day for the Copenhagen climate data.

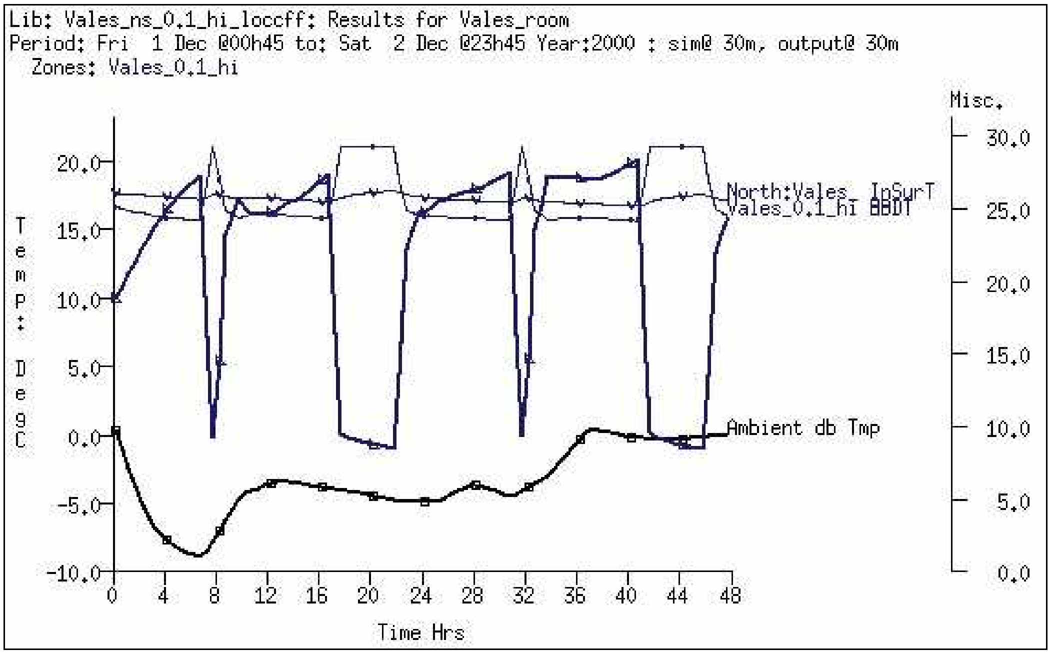
In this case the data is for the super-insulated (0.1) house and the high occupancy / gains scenario. It can be seen that during the occupied and awake period both the high and low thermal mass houses have acceptable comfort levels with less than 10% PPD.



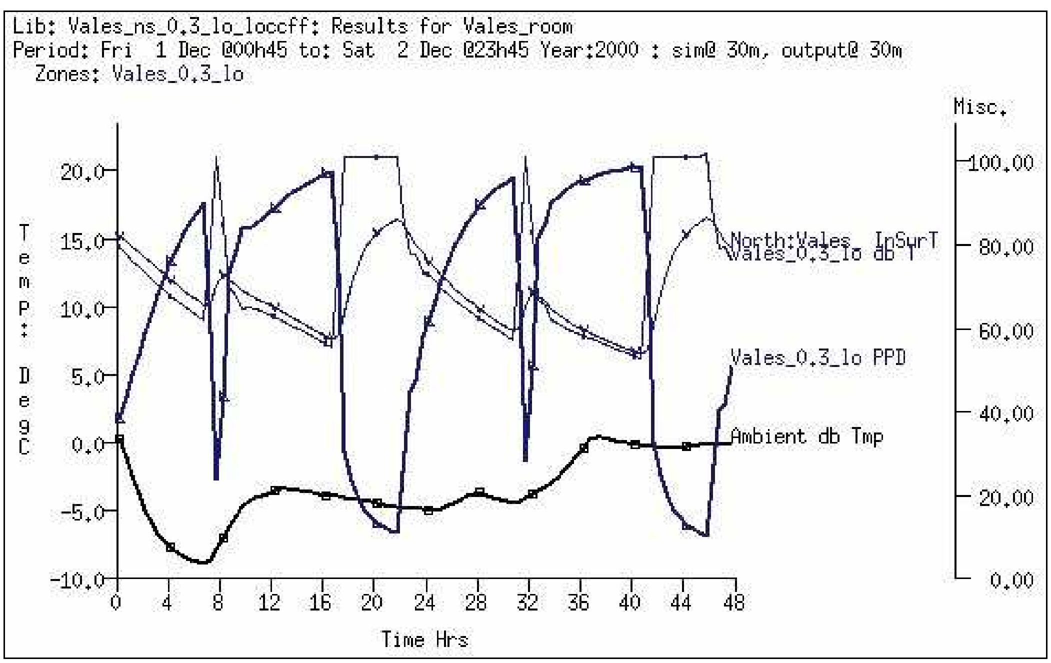


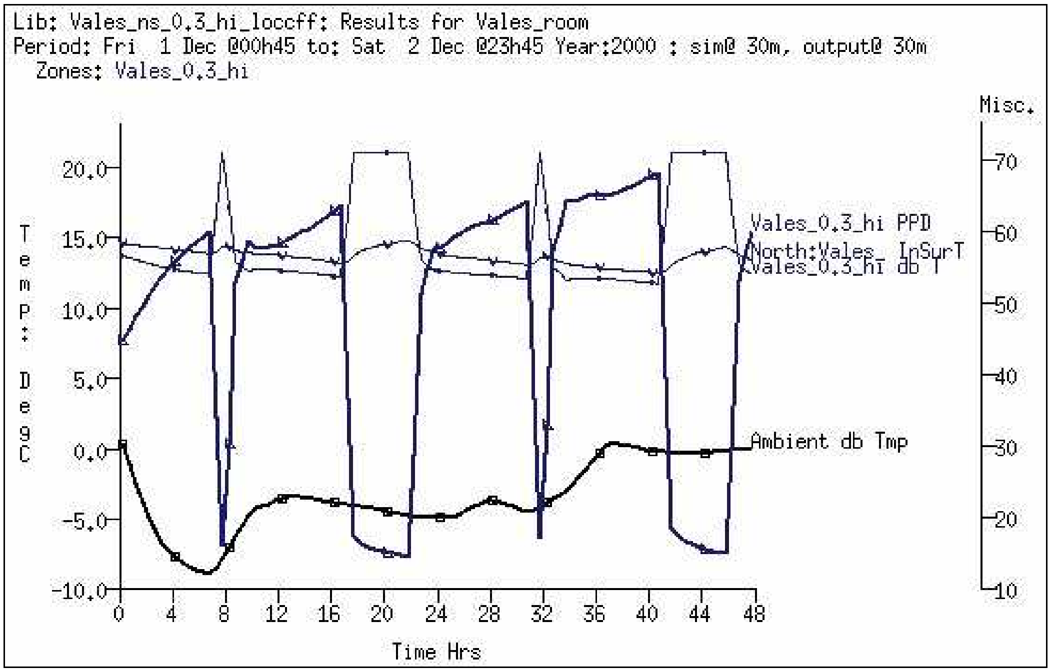

Similar data in the next two graphs again for the super-insulated (0.1) house but this time for the low occupancy / gains scenario is shown in figures 9 and 9 below. It can be seen that during the brief period in the morning and the evening heating period both the high and low thermal mass houses have acceptable comfort levels with less than 20% PPD achieved on this coldest day, both houses do achieve less that 10% PPD but in the case of the low mass house this is only achieved around 7pm, the high mass house performs marginally better.

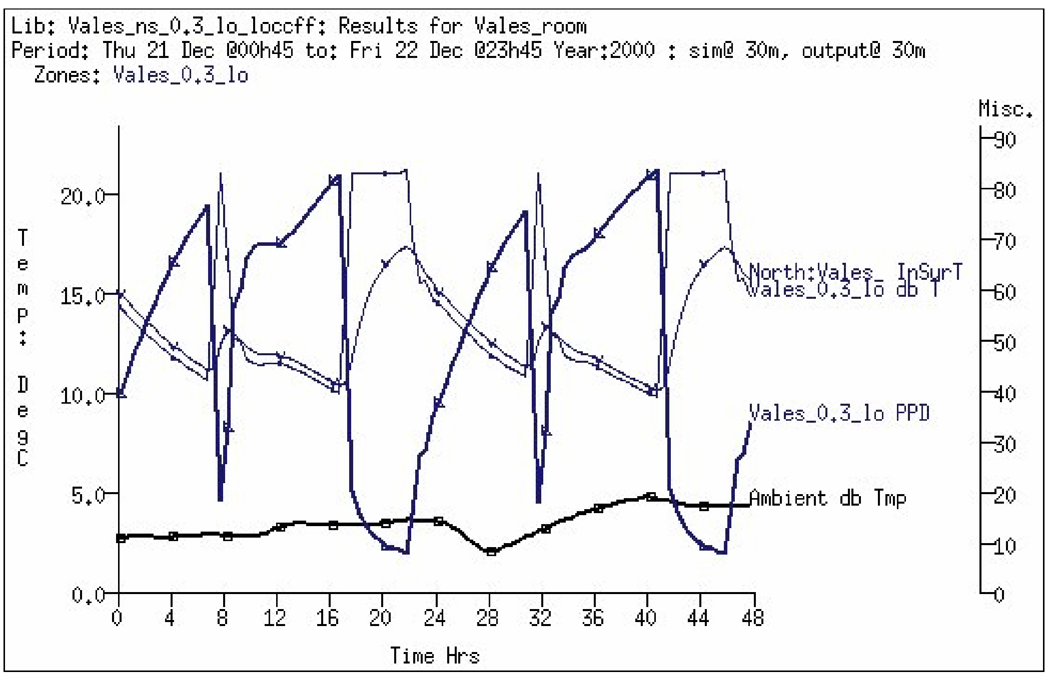




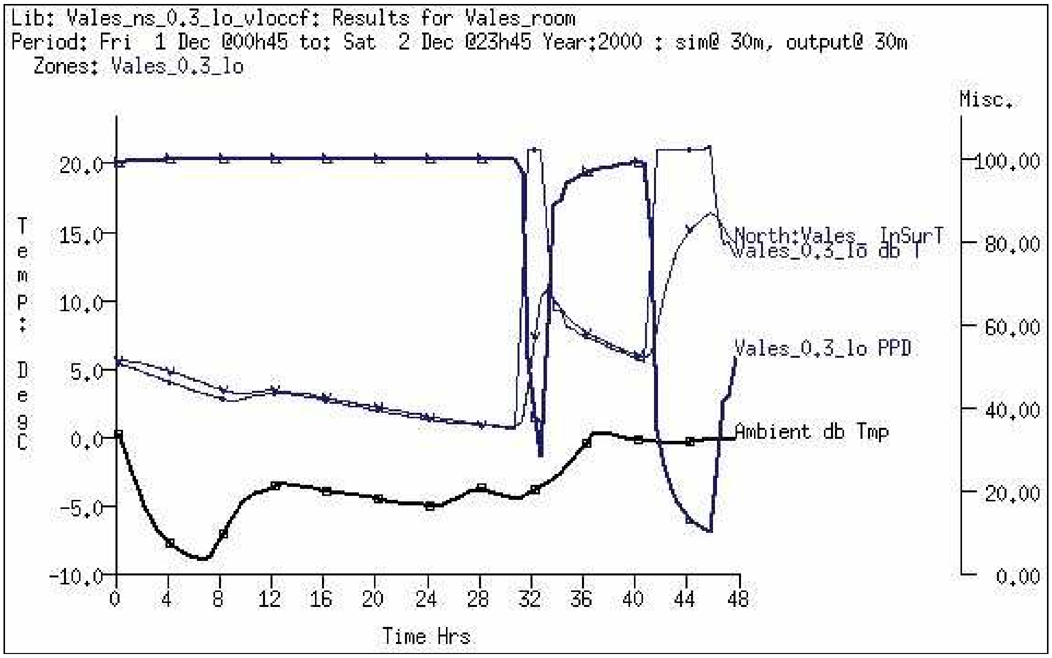

The next two figures show the 2005 regulations (0.3) house, again for the low occupancy / gains scenario. In this case the houses will not achieve the 'perfect comfort' condition (< 10% PPD) but do generally achieve 'slightly cool but acceptable' comfort levels (< 26% PPD). The high mass house performs slightly better during the short morning heating periods and at the beginning of the evening heating period, this appears to be due to the low temperatures in the low mass house when unoccupied and overnight. This could lead to the occupants extending the heating period in the low mass house (starting 1 hour earlier or running at a setback level). The next graph shows the low mass house during a less severe weather period and shows the same effect but at a lower level.

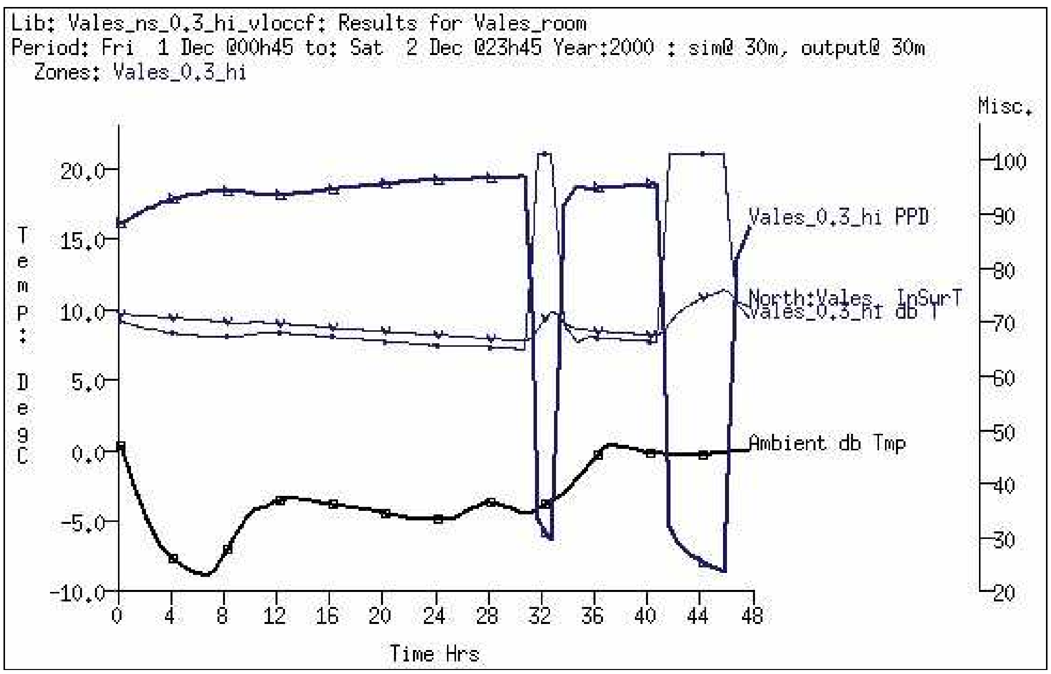





The next two figures below show the 2005 regulations (0.3) house for the very low occupancy / gains scenario, the two days shown are for the Friday which is the coldest day of the year and the Saturday that follows. In this case the house will not achieve the ‘perfect comfort’ condition (< 10% PPD) but generally achieve less than 35% PPD. The low mass house reaches ‘slightly cool but acceptable’ comfort levels (< 26% PPD) by around 7pm but the high mass house does not reach this level until 8.30pm. The best level achieved by the end of the evening heating period is around 11% PPD in the low mass house and around 24% PPD in the high mass house. The low mass house performs slightly better in this case due to lower thermal inertia than the high mass house when unoccupied during the weekdays.




Based on this detailed analysis of thermal comfort it was concluded that for the 2005 buildings regulation (0.3) low mass house in the northern climate with low occupancy may require some additional heating and the 6% heating energy benefit of low thermal mass indicated by the summary statistics may be offset by this and that either the low and the high mass constructions would then perform equally well from a heating point of view. A revised summary table is given below:

| Building Standard | Climate | Demand / Gain Scenario | | | |
|---|---|---|---|---|---|
| | | V low | Low | Std | High |
| 1999 Regulations ( 0.45 ) | North | 52% | 15% | 10% | - |
| 2005 Regulations ( 0.3 ) | North | 53% | - | - | -7% |
| UK Advanced ( 0.1 ) | North | 20% | -6% | -12% | -19% |
| 2005 Regulations ( 0.3 ) | South | 41% | - | -8% | -14% |
| UK Advanced ( 0.1 ) | South | - | -14% | -60% | -100% |

# Chapter 7:

# ESP-r investigation into the impact of thermal mass, insulation, and ventilation on cooling demand across UK climates and occupancies

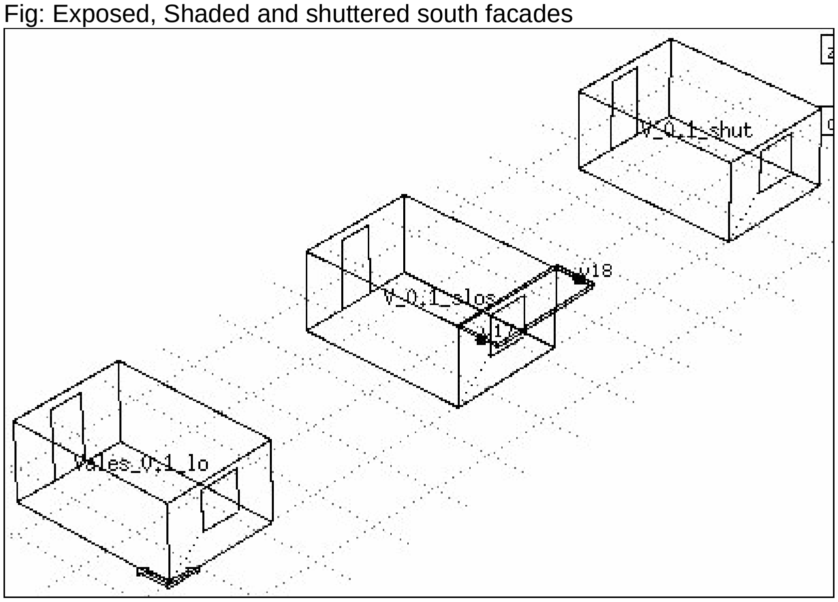
### 7.1 Cooling investigation methodology

In order to simulate the effect of thermal charging and discharging over the summer period simulations were run from 1st June through 30th September.

The 'Vales room' was duplicated and a second room created with a 1.25m shade overhanging the south façade, this shade dimension was picked to provide good shading during the summer but not have significant impact on useful solar gain during the winter. In practice this shading element could be realised as a roof overhang, balcony or purpose built shade above the south face of the building.

The 'Vales room' was duplicated again and a third room created to simulate the window covered by an opaque shutter. This case was realised by replacing the window with a wall element where the u-value had been adjusted to be the same as for the original glazed element.

Fig: Exposed, Shaded and shuttered south facades




The table below shows the summer temperatures for the climate files available in ESP-r. It can be seen that Jersey which was chosen to represent the southern extent of the climate range for the winter heating evaluation does not represent the most extreme summer cooling requirements as both Gatwick and Birmingham have warmer summers. The available Birmingham climate data was chosen as representative of a hot UK summer and the Paris climate file was used to investigate more extreme conditions.

| Climate | lat. | June max | June ave | July max | July ave | Aug max | Aug ave | Sept max | Sept ave |
|---|---|---|---|---|---|---|---|---|---|
| Gatwick | 51.5 | 31 | 15 | 27 | 17 | 29 | 17 | 21 | 14 |
| Birmingham | 52.5 | 25 | 14 | 28 | 17 | 30 | 16 | 20 | 13 |
| Jersey | 49.2 | 26 | 14 | 28 | 16 | 27 | 17 | 20 | 15 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Paris | 48.7 | 26 | 17 | 30 | 19 | 30 | 20 | 27 | 16 |

Initial investigations confirmed that the ‘Standard’ occupancy / gain scenario (daily occupancy, average gains) and ‘High’ occupancy / gains scenario (constant use, high gains) used for the heating evaluation were worst case for summer overheating potential and these were used in the cooling investigation. These scenarios are summarised in tables below.

Table: Gains for ‘Standard’ Scenario

| Gain (W) | 0 – 7 | 7 - 9 | 9 – 17 | 17 - 22 | 22 – 24 |
|---|---|---|---|---|---|
| Occupants | 40 | 60 | 0 | 60 | 40 |
| Lights | 0 | 25 | 0 | 50 | 0 |
| Cook / Appl. | 43 | 125 | 43 | 125 | 43 |
| Hot Water | 10 | 60 | 10 | 60 | 10 |

Table: Gains for ‘High’ Scenario

| Gain (W) | 0 - 7 | 7 - 9 | 9 - 17 | 17 - 22 | 22 – 24 |
|---|---|---|---|---|---|
| Occupants | 40 | 60 | 45 | 60 | 40 |
| Lights | 0 | 25 | 17 | 50 | 0 |
| Cook / Appl. | 43 | 125 | 116 | 125 | 43 |
| Hot Water | 10 | 60 | 44 | 60 | 10 |

Two ventilation patterns were used in the investigation, the first labelled ‘summer ventilation’ is a constant 4.5 ac/h which is to represent windows constantly open, the second labelled ‘night cooling’ is 4.5ac/h from 6pm until 8am and 0.45ac/h during the day between 8am and 6pm which represents windows opened only during the cooler parts of the day.

Both of the evaluated ventilation schemes are simple and designed to represent normal practice in housing. A more advanced ventilation technique which could give enhanced cooling (or reduced heating requirement in winter!) would be to employ ground air cooling ventilation where the input air is sourced via an underground heat exchanger [28]. Another technique would be to employ an automated ventilation control system which is actuated by internal and external temperature sensors [61].

### 7.2 Cooling investigation results

#### 7.2.1 Detailed analysis

The maximum temperatures should be viewed in the context of the comfort of the occupants. The ASHRAE Fundamentals chapter 8 [60]on thermal comfort gives the maximum summer comfort level as 26 – 27 degrees dependent on humidity, this accords with the reported turn on temperature for air conditioning in offices of 26 degrees [62]. However it is also reported that when external temperatures are elevated then internal temperatures up to 28 - 28.5 degrees can be tolerated without discomfort [8,62].

The table below shows the maximum dry bulb temperature experienced for the 3 different 'Vales-rooms' (south window exposed, shaded and shuttered) for the case of the Birmingham climate and the standard occupancy / gain scenario.

Only the high thermal mass construction with the south window shaded or shuttered maintains the room temperature within the ASHRAE maximum (i.e. 26-27 deg) for comfort. The low thermal mass construction meets the Evans / Vales maximum comfort temperature of 28-28.5 degrees only for the shuttered case.

Table 9: Max db temp: Advanced std (0.1), Birmingham, Standard occupancy / gain scenario.

| south window solar exposure | low thermal mass | | high thermal mass | |
|---|---|---|---|---|
| | summer vent | night cool | summer vent | night cool |
| Exposed | 31 | 33 | 27.5 | 27.5 |
| Shaded | 29 | 29 | 26 | 25.5 |
| Shuttered | 27.5 | 26 | 25 | 24 |

The high mass room maintains significantly lower maximum temperatures than the low mass room. For the summer ventilation case the maximum temperatures in the low thermal mass room are 3.5, 3 and 2.5 degrees cooler for the case of the exposed, shaded and shuttered south windows respectively.

It is also clear that the shading and shuttering of the window have large effects for all constructions and ventilation schemes with the best performance being from the shuttered window which excludes all solar gain. (The shaded window blocks direct radiation but admits diffuse solar radiation.)

The night cool ventilation scheme (0.45 ac/h 8am – 6pm, 4.5 ac/h 6pm – 8 am) gives lower maximum temperatures than the summer ventilation (4.5 ac/h) for high thermal mass construction where the window is shaded or shuttered and for the low thermal mass construction for the shuttered case only. The night cool ventilation is significantly worse for the low thermal mass construction where the south window is exposed. Further analysis shows that the night cool gives a benefit only on the hottest days when there is limited daytime cooling available to counteract daytime solar gains.

The figures below give examples of the high and low thermal mass buildings for the different ventilation schemes. The night cooling ventilation scheme for the standard occupancy is somewhat mismatched and the temperature peaks would be reduced if the evening gains period was delayed until there was cooling available from external air (long low energy lunch – late evening meal?) , in this evaluation the evening gains period started at 5pm but the night ventilation period started at 6pm. Optimisation of ventilation would have to be able to respond to dynamic changes in weather and could realistically be realised only through automated control based on internal and external temperature sensing [61].

Fig: Advanced construction (0.1), low thermal mass, Birmingham, Standard Gains, Summer ventilation scheme (constant 4.5ac/h)

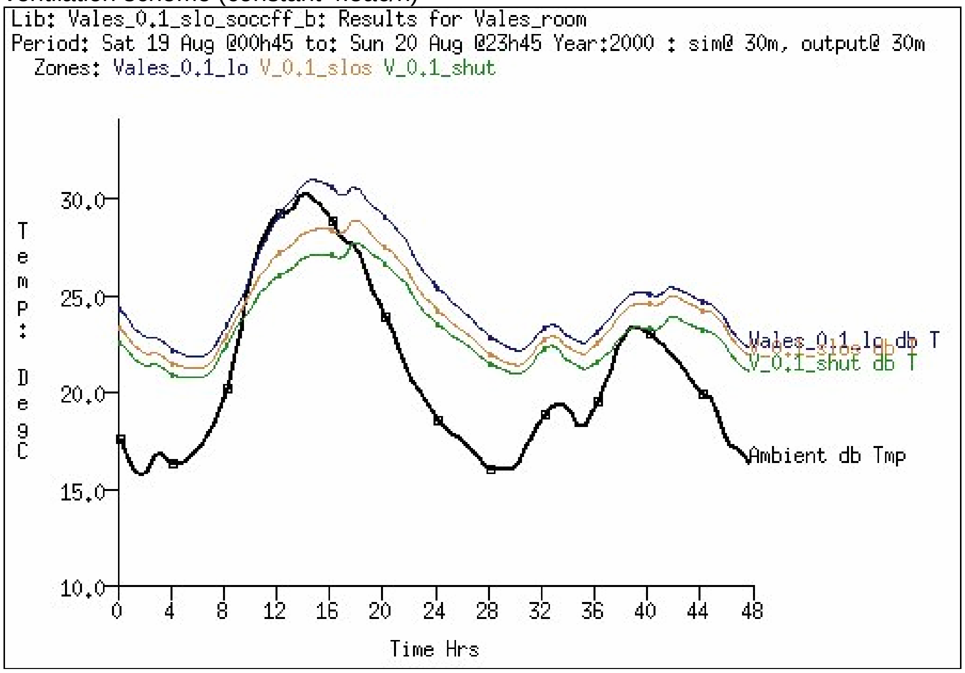



Fig: Advanced construction (0.1), high thermal mass, Birmingham, Standard Gains, Summer ventilation scheme (constant 4.5ac/h)

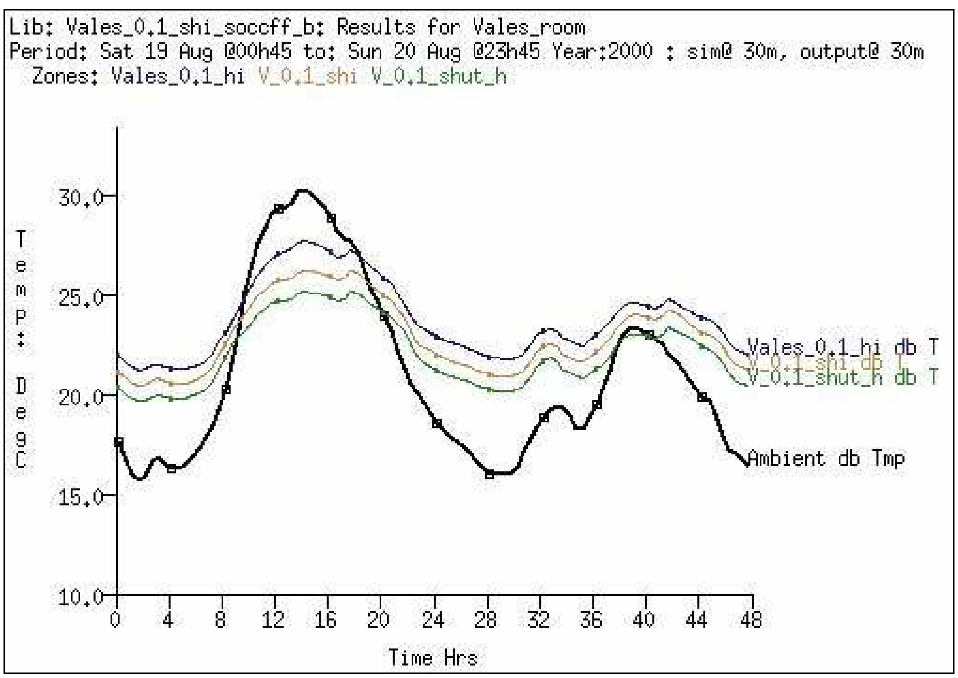


Fig: Advanced construction (0.1), low thermal mass, Birmingham, Standard Gains, Night cooling ventilation scheme (4.5ac/h 6pm – 8am, else 0.45 ac/h)

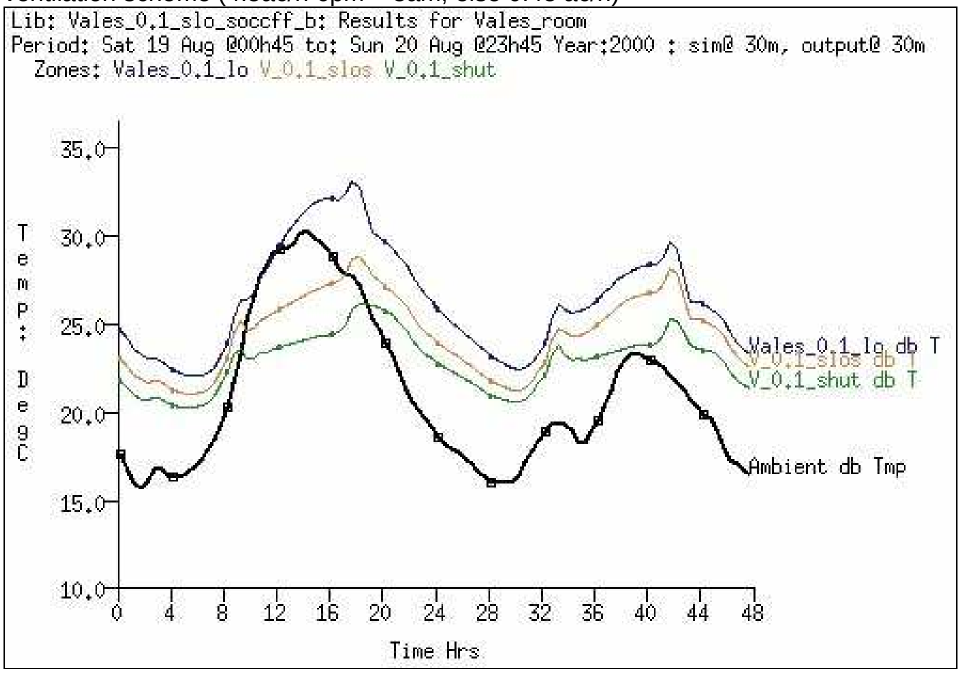
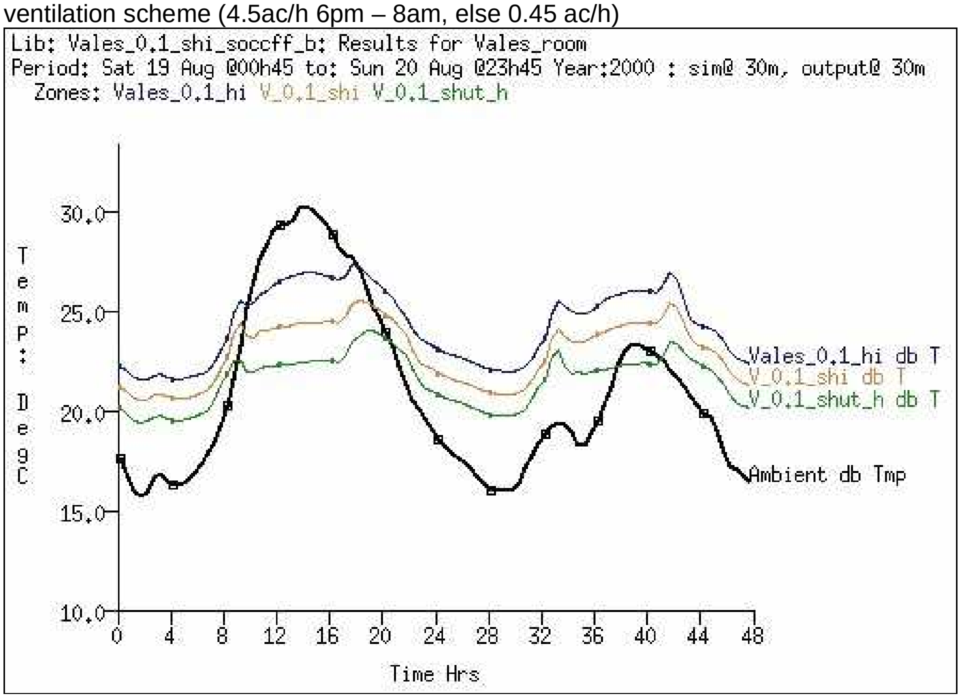



Fig: Advanced construction (0.1), high thermal mass, Birmingham, Standard Gains, Night cooling ventilation scheme (4.5ac/h 6pm – 8am, else 0.45 ac/h)




The analysis showed similar trends in the results for the advanced standard construction (0.1) with standard occupancy / gains in the Paris climate although in all cases the maximum temperatures are higher (Table below). Only the high thermal mass shuttered building was maintained within the ASHRAE maximum range (26-27 degrees). The shaded high thermal mass building and the shuttered low mass building maximum were however inside the Vales 28.5 degrees limit.

Table: Max db temp: Advanced std (0.1), Paris, Standard occupancy / gain scenario.

| south window solar exposure | low thermal mass | | high thermal mass | |
|---|---|---|---|---|
| | summer vent | night cool | summer vent | night cool |
| Exposed | 31.5 | 34 | 29 | 29.5 |
| Shaded | 30 | 30 | 28 | 28 |
| Shuttered | 28.5 | 28 | 27 | 26 |

The results for the advanced standard building in the Birmingham climate with the high occupancy / gains scenario (Table below) again show the high thermal mass house to maintain temperatures within the ASHRAE maximum (26-27) where the south window is shaded or shuttered while the only low thermal mass house to be within the Vales maximum (28.5) is the shuttered one. For this high occupancy / gains scenario the higher internal gains during daytime offset the benefits of 'night cooling' ventilation so that 'summer vent' (constant 4.5 ac/h) gives similar maximum temperatures in the high thermal mass house.

Table: Max db temp: Advanced std (0.1), Birmingham, High occupancy / gain scenario.

| south window solar exposure | low thermal mass | | high thermal mass | |
|---|---|---|---|---|
| | summer vent | night cool | summer vent | night cool |
| Exposed | 32 | 35.5 | 29 | 29 |
| Shaded | 30 | 31 | 27 | 27 |
| Shuttered | 28.5 | 28 | 25 | 25 |

Construction to the proposed 2005 regulations (next two tables) again gives the same trends for the Birmingham climate as the advanced construction except that for the high occupancy / gain scenario temperatures are generally higher and even in the shuttered case the low thermal mass building has peak temperatures above the Vales maximum of 28.5 degrees.

Table: Max db temp: 2005 reg's (0.3), Birmingham, Standard occupancy / gain scenario.

| south window solar exposure | low thermal mass | | high thermal mass | |
|---|---|---|---|---|
| | summer vent | night cool | summer vent | night cool |
| Exposed | 31 | 33 | 27.5 | 27 |
| Shaded | 29 | 29.5 | 26.5 | 25.5 |
| Shuttered | 28.5 | 28 | 26 | 24.5 |

Table: Max db temp: 2005 reg's (0.3), Birmingham, High occupancy / gain scenario.

| south window solar exposure | low thermal mass | | high thermal mass | |
|---|---|---|---|---|
| | summer vent | night cool | summer vent | night cool |
| Exposed | 32.5 | 35.5 | 28.5 | 28 |
| Shaded | 30 | 31.5 | 27 | 26.5 |
| Shuttered | 29.5 | 30 | 26.5 | 25.5 |

**7.2.2 Cooling Investigation – Results Summary:**

In general the high thermal mass building has lower maximum temperatures by around 3 degrees than the low thermal mass building. The high mass construction combined with shading or shuttering maintained temperatures within the ASHRAE guidelines for comfort for the UK climate simulations. For the Paris climate shutters were a requirement to meet this criterion.

The low thermal mass building generally failed to meet the ASHRAE comfort maximum (27) but was able to maintain maximum temperatures within the Vales maximum (28.5 degrees) if shutters were used for all cases except the case of high gains / 2005 regulations where maximums were 29.5 - 30 degrees. Alternate passive cooling systems using cooler than ambient air through ground pipes [ ] etc could be considered for lower thermal mass buildings and this is demonstrated on the IEA Thening example house [28] but this is not yet a standard technique.

A parameter which should be considered against these maximum temperatures is the frequency at which they occur. For the Birmingham climate file ambient temperatures over 25 degrees are experienced during 9 days of the year, for the Paris climate file the figure is 29 days (Table below). It appears that in general temperatures over 27 degrees are rare for the more northern of the UK climates.

Table 9: High temperature days for ESP-r UK, Paris and Copenhagen climate files

| Location | Latitude | Days with T > 25deg | Days with T > 26deg | Days with T > 27deg | Days with T > 28deg | Days with T > 29deg | Days with T > 30deg |
|---|---|---|---|---|---|---|---|
| Paris | 48.7 | 29 | 22 | 16 | 8 | 7 | |
| Jersey | 49.2 | 5 | 2 | 1 | | | |
| Gatwick | 51.5 | 11 | 7 | 3 | 3 | 1 | 1 |
| Kew | 51.7 | 5 | 3 | 1 | | | |
| Birmingham | 52.5 | 9 | 4 | 4 | 2 | 2 | 1 |
| Finningley | 53.5 | 10 | 7 | 5 | 3 | 1 | 1 |
| Dublin | 53.4 | 0 | | | | | |
| Belfast | 54.7 | 0 | | | | | |
| Oban | 56.4 | 2 | | | | | |
| Copenhagen | 56.5 | 5 | 2 | | | | |

The data above based on the available climate files is consistent with the climate analysis in CIBSE thermal comfort documentation [63], the CIBSE graph is shown below.

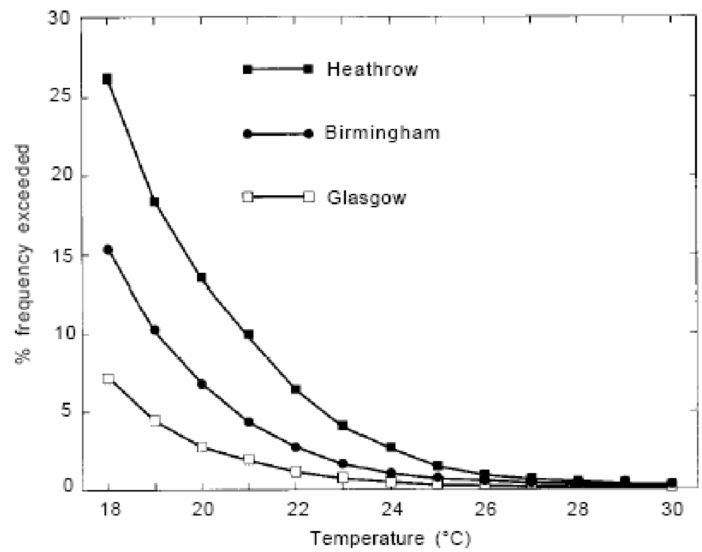



**Figure 1.16** Temperature frequency distribution for 3 UK sites

Climate, thermal mass, the avoidance of direct solar gain, ventilation and casual gains are all shown to be important factors in maintaining comfortable temperatures and avoidance of summer over-heating. High thermal mass together with shading or shuttering allows comfortable temperatures to be maintained. Avoidance of summer over-heating is most important in the warmer UK climates.

# Chapter 8:

# The role of thermal mass, insulation, and ventilation in sustainable housing across UK climates and occupancies; discussion, key issues and recommendations

### 8.1 Discussion

The heating investigation allows an attempt to be made to explain the apparently conflicting views on thermal mass highlighted in the introduction section.

The high mass house in the 2004 Finney article in Building for the Future [23] was built in 1976 to advanced standards for its time but these were looser than the proposed 2005 regulations characterised here, this property was also acknowledged to have significant cold bridging further increasing the effective U-value, in contrast the low mass house was moved into in 1998 and was closer to the proposed 2005 regulations, the experience of the high mass house requiring more heating is consistent with the finding of this study that high mass houses with poorer insulation require more heating.

The 1976 Architects Journal article [64] that was put forward by Finney as providing data showing that high thermal mass buildings consumed at least 10% more energy for heating than low thermal mass buildings was based on construction standards that included u-values for wall, roof and floor of 5 W/m2C, ventilation rate of 2 ac/h and a design temperature delta of 20 degrees. High thermal mass buildings to these extremely poor standards would be expected to perform badly but these results are not relevant to more modern building standards.

The 40% reduction in heating demand in New Zealand houses with the addition of the high thermal mass ground floors sited in the Vales book [8] is consistent with this study which confirms that in lower latitudes the addition of thermal mass would in general reduce heating demand.

The results of this investigation are consistent with the New Zealand studies [56,57] which showed that in lower latitudes (Auckland latitude 37 deg) there is a significant benefit of high mass but that at higher latitudes (Invercargill latitude 47 deg) the benefit becomes relatively smaller.

The successful UK high thermal mass low energy houses (Vales Autonomous, Hockerton, BedZED) are all super-insulated to advanced standards (0.1), have heat recovery ventilation and are situated in the southern half of the UK and so fit well within the parameters where high thermal mass gives reduced heating demand. BedZED (and to some degree Hockerton) aims to maximise occupancy through provision of on site workspace (this also is aimed at reducing travel).

The passive heat recovery ventilation employed at BedZED would appear to have some potential benefits over the mechanical systems employed at Hockerton and the Autonomous house in terms of reliability and no electricity requirement however technical details need to be studied and applicability determined (stack height, controls etc).

The Passive House standard of < 15 kWh/m2 space heating requirement to be achieved through super-insulation and MVHR appears achievable across all occupancy / gain scenarios and UK climates for both high and low mass constructions in this study.

The IEA Sustainable Solar Housing demonstration houses have a range of constructions from thermally light timber frame, through light frame with concrete flooring to the heaviest which have multiple high mass elements. In general there is a trend towards higher thermal mass in more southerly climates for purposes of cooling.

This investigation shows that for the southern UK climate high thermal mass combined with shading or shuttering can maintain comfortable internal temperatures and avoid summer overheating even on days when the external day time temperatures are above the temperature to allow conventional ventilation cooling. The low thermal mass construction was shown to be somewhat marginal for comfort in these conditions even when shuttered. The low mass building could lead to increased probability of the adoption of air conditioning cooling with the large energy use associated with these systems. Alternatively ground pipe air cooling or a similar system could be employed as an alternative.

The 2002 UK Advanced standard (based on the 1996 UK Zero Heating standard) drives insulation and air-tightness in the right direction but is less demanding in air tightness and glazing u-value than Passive-House. The Advanced standard is not as rigorous as the Passive House standard in the area of ventilation and heat recovery.

The requirement of high thermal mass in conjunction with the super-insulation in the UK Advanced standard gives clear benefits in terms of reduced heating requirements except in the case of very low occupancy / gains (weekend use only scenario) in more northerly climates. The benefit of the high mass for avoidance of summer over-heating in southern UK climates can also be very significant and avoid the perceived need for air conditioning. The Passive-house standard is less prescriptive than the UK Advanced standard and this allows freedom to use alternate techniques such as ground pipes to achieve cooling.

It would be helpful if synergy of low energy housing standards could be achieved across Europe, the Passive House and UK Advanced have similarities in terms of insulation and air-tightness but diverge on glazing U, ventilation and thermal mass.

The UK building regulations have been regularly improved but could still be greatly improved in terms of insulation standards (and thermo-graphic survey to check compliance), air-tightness specification (set spec, pressure test to check compliance) and ventilation (specify heat recovery with a minimum % recovery rate). Also the inclusion of guidance on the appropriate use of thermal mass would be a move in the right direction.

The supply technology used for the dwelling may also influence the decision on thermal mass. In the case of renewable supplies the energy storage capability of high thermal mass may offer some additional advantages e.g. where wind power or air heat pumps generate energy intermittently.

The ‘Vales room’ used in this study has demonstrated the effects of the chosen factors on heating and cooling requirement. Where actual houses have less external wall they will behave as if they have a lower overall u-value, where there are larger window areas there will be higher overall u but increased solar gains. Calculations of u values in actual constructions should take account of the effects of thermal bridging.

The 100% convective heating with ideal control used in the Vales room evaluation is similar to the Passive-House ventilation air heating system. Modern gas fired central heating systems with wet ‘radiators’ can be typically 70-90% convective. The appropriate heating type should be modelled for a specific case.

It is strongly recommended that energy simulation of proposed housing designs across occupancy / gains and climate should become a requirement.

**8.2 Summary and conclusions from ESP-r investigation**

For winter heating the influence of insulation standards, ventilation, orientation, occupancy / gains, thermal mass and climate are quantified and the relative impacts discussed.

Insulation, climate, ventilation and orientation are shown to have the largest effects overall although thermal mass can also important in specific climate and occupancy / gain cases.

For 'Advanced' construction standards (around 0.1 u-values) the high thermal mass can give significant reduction in heating in most cases with the exception of the very low occupancy / gain in northern climate case.

For 2005 building regulations the high mass construction is favourable for heating in the southern climate with the exception of the very low occupancy / gain scenario (weekend use only).

For heating in the northern climate the high mass is favourable for higher occupancy / gain scenarios but low mass performs better in lower occupancy / gain scenarios.

For summer cooling the climate, thermal mass, shading, shuttering, ventilation and casual gains are all shown to be important factors in maintaining comfortable temperatures and avoiding over-heating. High thermal mass together with shading or shuttering allows comfortable temperatures to be maintained. Avoidance of summer over-heating is most important in the warmer UK climates.

High thermal mass construction generally performs best in buildings built to the proposed 2005 regulations or the UK 'Advanced standard', the benefits are greatest in the southern UK climates. The exception is the case of very low occupancy / gains in the northern UK climates where low thermal mass may perform best. This is summarised in table 9 below.

| UK climate zone | Building Regulation | Type of construction indicated by 'Vales room' with 100% convective heat delivery and ideal control (Heating (H) or Cooling (C) benefit in brackets) | | | |
|---|---|---|---|---|---|
| North | 0.3 | Low thermal mass (H) | Either | High thermal mass (C) | High thermal mass (H,C) |
| | 0.1 | Low thermal mass (H) | High thermal mass (H) | High thermal mass (H,C) | High thermal mass (H,C) |
| South | 0.3 | Either | High thermal mass (C) | High thermal mass (H,C) | High thermal mass (H,C) |
| | 0.1 | High thermal mass (C) | High thermal mass (H,C) | High thermal mass(H,C) | High thermal mass (H,C) |
| Occupancy / Gains Scenario | | Very Low | Low | Standard | High |

It is recommended that building energy simulation is carried out at the design stage to define the optimum for the appropriate range of climate and occupancy / gain scenarios.

# Chapter 9:

# Sustainable housing; conclusions and future work

### 9.1 Conclusions

The two area's where this thesis makes a contribution are firstly; the debate on standards and metrics that should be applied to achieve sustainable housing, and secondly; the debate on the impact of thermal mass, ventilation and insulation on sustainable housing across the range of UK climates and occupancies.

A historical perspective and review of current thinking and best practice examples is presented together with concise summaries of UK and European standards, assessment methods and metrics. The different approaches are compared, key issues identified and recommendations are made for both improvements and further investigations.

The Ecohomes assessment scheme is found to provide a good rating for overall sustainability but weaknesses are identified in energy performance and recommendations for improvements are put forward.

The first area of weakness is that the maximum award of 'Excellent' is achieved for a score of 70%, this allows a development to be 'Excellent' which scores 0% for the energy section. It is proposed that the EcoHomes 'Excellent' criteria is differentiated by the addition of 1 to 5 stars for scores beyond 70% i.e. 'Excellent 5-star' rating if > 95% etc.

The second improvement proposed is to increase the resolution of the points awarded for performance below 20 kgCO2/m2 pa to allow differentiation of more advanced houses, at present they fall into two 10 kgCO2/m2 pa wide buckets.

The third suggested improvement would be to replace the SAP and CI metric with the EcoHomes Ene1 calculated CO2 kg/m2 pa. metric as this would allow the environmental impact of lights, appliances and cooking to be included.

The impact of energy supply technologies on sustainability is shown to be large and the approaches taken in the different examples and standards are discussed, this is discussed further in the future work section.

The conflicting views on the importance of thermal mass, solar gain, and ventilation method for sustainability in housing are highlighted by the comparison and are investigated in the second half of the thesis.

The different opinions on thermal mass, insulation standard and ventilation strategy are reviewed in some detail. Simple calculations are then used to illustrate the potential benefits and issues with high and low thermal mass and the significance of insulation, orientation, ventilation, occupancy and climate. A more detailed analysis of the influence of these factors on heating and cooling requirements is carried out across a range of UK climates and occupancies using ESP-r. The scope of the investigation covers the UK 1999 and proposed 2005 building regulations, the UK advanced standards and the European Passive-house standard.

The influence of thermal mass on heating is shown to depend on the occupancy / gain scenario, insulation standard and climate. For example the high mass house modelled required > 50% more heating than the low mass house for the very low occupancy, 2005 building regulation, northern climate case but required 100% less heating for the high occupancy, advanced standard, southern climate case. A matrix of results is presented and an explanation given for the conflicting views on thermal mass and its impact on heating demand. Insulation, climate, ventilation and orientation are shown to have the largest effects overall on heating energy requirements although thermal mass can also be important in specific climate and occupancy / gain cases.

Summer cooling is also investigated. It is shown that climate, thermal mass, shading, shuttering, ventilation and casual gains are all important factors in maintaining comfortable temperatures and avoiding summer over-heating. High thermal mass together with shading or shuttering allows comfortable temperatures to be maintained without cooling. Avoidance of summer over-heating is most important in the warmer UK climates.

Overall, high thermal mass construction generally performs best in houses built to the proposed 2005 regulations or the UK 'Advanced standard', the benefits are greatest in the southern UK climates. The exception is the case of very low occupancy / gains in the northern UK climates where low thermal mass may perform best. A matrix is presented (and reproduced below) showing the appropriate use of thermal mass for the best heating and cooling performance of the example building used in this study.

| UK climate | Building Regulation (wall u) | Type of construction indicated by 'Vales room' with 100% convective heat delivery and ideal control (Heating (H) or Cooling (C) benefit in brackets) | | | |
|---|---|---|---|---|---|
| North | 0.3 | Low thermal mass (H) | Either | High thermal mass (C) | High thermal mass (H,C) |
| | 0.1 | Low thermal mass (H) | High thermal mass (H) | High thermal mass (H,C) | High thermal mass (H,C) |
| South | 0.3 | Either | High thermal mass (C) | High thermal mass (H,C) | High thermal mass (H,C) |
| | 0.1 | High thermal mass (C) | High thermal mass (H,C) | High thermal mass(H,C) | High thermal mass (H,C) |
| Occupancy / Gains Scenario | | Very Low | Low | Standard | High |

The Passive House Standard, UK 2005 Proposed Building Regulations and UK Best Practice guidelines are reviewed against the results of the ESP-r investigation and some observations made.

It is strongly recommended that building energy simulation is carried out at the design stage of new builds and refurbishments to define the optimum construction for the appropriate range of climate and occupancy / gain scenarios.

### 9.2 Future work

The thesis forms a good starting point from which to contribute to the debate on a sustainable building code being championed by the ODPM and which is planned to have an output in 2006/7.

The lack of a tool in the best practice literature which allows easy analysis of the optimum combination of sustainable energy options and provides the financial and environmental metrics associated with any combination selected was highlighted during the review. A tool along the lines of the ”GENcalc” tool is envisaged as being worthy of development. Current development along the lines of RETscreen and MERIT may already be addressing this area but has not so far reached the best practice literature.

The ESP-r investigation in section could be extended to investigate the impact on heating energy requirements of different heating systems i.e. 100% convective, wet radiator system with different radiative / convective components, under-floor heating etc.

The investigation could be further extended to quantify the total life cycle energy for a range of construction exemplars rather than just the energy in operation. (It should be noted that low thermal mass can be achieved within a high mass construction envelope through dry-lining and flooring and that high mass can be realised in a timber frame construction through high mass floors and internal walls (clay blocks, water etc)).

Further investigation into health and comfort impact of humidity levels and other environmental properties in airtight constructions for different ventilation schemes and the effect of building types, materials, breathing walls etc could be pursued.

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