# Sustainable Housing Standards: Use of simulation in design.

**P.G.Tuohy<sup>\*1</sup>, C. Johnstone<sup>1</sup>, L. McElroy<sup>2</sup>** <sup>1</sup>The Energy Systems Research Unit, University of Strathclyde, Glasgow, G1 1XJ, UK <sup>2</sup>The Lighthouse on Sustainability, Glasgow \* Corresponding Author, email: tuohy@esru.strath.ac.uk

#### Abstract

Current guidelines for sustainable housing including the EU 'Passivhaus' and UK 'Advanced' standards are reviewed along with UK building standards. Areas of divergence between the guidelines are identified in the specification of insulation level, ventilation strategy and use of thermal mass. It is shown that a simple model used to illustrate the benefit of thermal mass can also illustrate potential problems. A detailed investigation based on dynamic simulation is carried out into the performance of different constructions across a range of climates and different occupancy and gain scenarios. The results show how key parameters can affect building performance including occupant comfort, heating energy requirements and summer overheating. The conclusion of the study is that the current guidelines have limits to their applicability and that simulation should be used in the design of sustainable housing. The simulation should consider the range of climate and occupancy scenarios appropriate to the current situation and potential future scenarios.

Keywords: Sustainable housing, building performance, Building simulation, Passivhaus.

#### 1. Introduction

There are many standards and guidelines relating to sustainable housing and they appear to give conflicting advice.

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 and the project has monitored 250 across Switzerland, Germany, Austria, France and Sweden [1]. The passive house target is total final energy demand for space heating, domestic hot water and household appliances below 42 kWh/m<sup>2</sup> pa and space heating below 15 kWh/m<sup>2</sup> pa. There is no specification relating to thermal mass, passive houses have been realised in thermally light and thermally heavy constructions. The passive-house standard specifies that mechanical heat recovery ventilation is used. Many Passive Houses are included in the IEA Sustainable Solar Housing demonstration [2]. The 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 low mass wall and roof 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 'Advanced' standard. In general the amount of thermal mass increases the more southerly the location apparently driven by summer cooling concerns.

The UK Housing Energy Efficiency Best Practice Program specify the UK 'Advanced' standard [3] based on the previously specified 'Zero Heating' standard where floor, wall and ceiling constructions are of high thermal mass [4]. Well documented examples of 'Advanced' housing in the UK are BedZED [5], Hockerton [6] and the Vale's Autonomous house [7]. Professor Brenda Vale and Dr Robert Vale are the authors of the UK 'Zero Heating' standard on which the UK 'Advanced' standard is based. The Vales had previously designed, built and lived in the superinsulated, high thermal mass 'Autonomous House' and their experiences are documented in 'The New Autonomous House' [7]. 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.

There have been several investigations published [8] on the influence of thermal mass and insulation on space heating (and cooling) across New Zealand temperature zones (latitudes 32 to 47) which show a beneficial impact of thermal mass that decreases with distance from the equator. The UK climate zone extends beyond the latitudes covered by these studies.

CIBSE in their Guide F [9] state "a less thermally massive building would have shorter preheat periods and use less heating energy". David Finney 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 [10]. He quotes the Architects Journal: "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 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".

Building Standards	UK Advanced	Passive-house	UK 2005 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
Glazing / Door U	1.5	0.75	2
Air-tightness	1ac/h@50Pa	0.6ac/h@50Pa	No spec
Ventilation	PS, a-PS, MHR	MHR	N, PS, MHR, ME
Mass (thermal)	High	No spec	No spec

Table 1.	Comp	arison	of	standards	for	housing.
						0

The 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 analysis the operational energy demand is the most important factor [11, 12].

Historically the regulatory focus in the UK has been on winter heating loads and thermal comfort but with the recent trends towards higher temperatures and the prospect of these trends continuing then more focus on building design to avoid summer overheating is required.

The objective of this study is to demonstrate the impact of key variables on operational energy use and comfort in housing and also provide some insight into the areas where the guidelines diverge.

## 2. The Model

Brenda and Robert Vale put forward a simple calculation model illustrating the role of thermal mass, insulation and ventilation. They illustrate this model by applying it to a representative section of their house which will be referred to as the 'Vales Room'. The theoretical Vales Room is very similar to the test buildings being used by UCLA to investigate thermal mass and ventilation for cooling in the Californian climate [13]. The basic argument behind the construction of the Vales 'Autonomous' house on which the UK 'Advanced' standard is based is that the high insulation and heat recovery ventilation minimise heat demand while the thermal mass allows any heat gains to be captured and become useful heat when required. It is postulated that the storage capacity can allow a building to survive cold spells without requiring heating. Similarly the simple model indicates 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. Negative aspects of thermal mass can also be postulated from this simple model. Gains may be highest when the occupants are in residence, in the high mass house the gains do not transfer as directly into increased temperatures 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. This simple model illustrates some principals but does not allow detailed analysis of realistic heating and cooling for comfortable temperatures in real climates. A more sophisticated dynamic model is required.

Fig 1. The simple model



### 3. The Investigation

The 'Vales room' was recreated in ESP-r in versions representing a range of constructions. For low mass, only low mass elements are within the insulation envelope (plasterboard, softwood, carpet etc.). For high mass the concrete elements are inside the insulation envelope and connected to the room air through plaster or clay tiles. For each construction type the insulation thickness was varied to represent the different insulation standards (Insulation standards labelled: '0.45' ='1999 regulations', '0.3' = '2005 regulations', '0.1' = 'Advanced'). Using the dynamic simulation tool it was possible to complete annual simulations for any combination in less than 1 minute. The graphs below show the different responses of the low and high thermal mass buildings to solar radiation for an October day, on this day the low mass building surface and air temperatures are warmed more rapidly so less evening heating is needed.





### 3.1 Heating season investigation

A full factorial investigation into annual heating energy requirement was run for the Vales room. Factors included low and high thermal mass, insulation levels, occupancy patterns (from very low occupancy / gains to high occupancy / gains), climate (varying from northern UK to southern UK climate), window orientation and ventilation rate. Throughout the investigation it was confirmed that comfortable conditions were being maintained using embedded PPD and PMV calculations.

The figure below shows an autumn to winter transition for 'Advanced' (0.1) and '2005 Regs' (0.3) insulation standards in the northern climate. The heating season starts on 1<sup>st</sup> November for the 'Advanced' and peak heating load is 0.5kW, for the '2005 Regs' (0.3) construction the heating start date is the 23<sup>rd</sup> Sept and peak heating load is 1.6kW.



Fig 3. 'Advanced' (0.1) and '2005 Regs' (0.3) heating start dates and peak loads

The graphs below show the annual heating energy requirement in  $kWh/m^2$  p.a. for the low and the high occupancy / gain scenarios. (X-axis key is: insulation standard, thermal mass, climate - north (C) or south (J)). It can be seen that climate and insulation standard have consistent effects where the effect of thermal mass varies with insulation standard, climate and occupancy / gains. It can be seen that while insulation standard and climate have consistent effects the impact of thermal mass depends on the other factors.

Fig 4. Annual heating requirements for low and high occupancy / gains scenarios, 0.45 ac/h.



Similar analysis was carried out across all the matrix elements. Only the 'Advanced' (0.1) insulation case with Mechanical ventilation and heat recovery (effective ventilation rate 0.21 ac/h) meets the 15kWh/m2 pa passive house standard across all scenarios.

### 3.2 Cooling season investigation

To investigate summer cooling further, versions of the 'Vales room' were created to represent the effects of shading and shuttering of the windows. 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 and these were used in the cooling investigation. Two ventilation patterns

were investigated, the first labelled 'summer ventilation' is a constant 4.5ac/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 mainly opened during the cooler parts of the day. Both of the evaluated ventilation schemes are simple and designed to represent normal practice by occupants. The Birmingham and Paris climate files in ESP-r were chosen to represent current hot summer conditions and a possible future UK climate. The table below shows an example of peak summertime temperatures. Temperatures of over 27 degrees are deemed to be comfortable and temperatures up to 28.5 degrees are within the allowable range as long as occupants have freedom to adapt, higher temperatures are generally considered unacceptable.

window 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 2. Max dry bulb temp: '2005 Regs' (0.3), Birmingham, Standard occupancy / gain scenario.

Thermal mass, ventilation patterns, climate and shading were seen to have significant effects.

#### **3.3 Ventilation investigation**

The cooling investigation made assumptions about ventilation rate, to investigate further a modelling exercise was carried out to investigate the influence of window and ventilation opening design on the airflows achieved in real climate conditions. An airflow network was constructed representing different window and ventilation opening types and simulations run during several hot UK climate periods.

Scenario (based on low thermal mass construction)	Max temp	Weekly hours> 28deg C	Mean air change rate (ac/h)
1. 2 top pivot windows – adjacent facades	30.9	7	1.4
2. As 1. but opposite facades (x-flow)	28.5	1	4
3. As 1. but with centre pivot windows	29.0	3.8	2.25
4. As 3. but with larger openings	28.1	0.4	3.5
5. As 1. but with high thermal mass	27.0	0	1.4

The investigation showed the importance of ventilation design in maintaining thermal comfort. The top pivot windows modelled in the base case (Scenario 1.) were restricted to a 10cm bottom opening area, the centre pivot windows had openings at both the top and the bottom. Again the effect of thermal mass on peak temperature was illustrated by this dataset.

#### 4. Discussion

The apparent conflicting views in the guidelines on thermal mass appear to be explained in this investigation, high mass poorer insulated buildings with lower occupancy and gains in more northern climates require more heating energy than lower mass alternatives while higher insulated buildings with higher occupancy and gains in more southern climates require less heating than lower mass alternatives.

The Passive House standard of < 15 kWh/m2 space heating 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.

For the southern UK climate, high thermal mass combined with adequate ventilation openings and shading or shuttering could maintain comfortable internal temperatures and avoid overheating. Low thermal mass construction can 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.

Each individual simulation in this investigation ran in less than a minute on a standard PC.

### 5. Conclusions

Insulation standard, ventilation strategy and orientation have consistent effects on heating energy requirements while the effect of thermal mass varies with insulation standard, climate and occupancy / gains scenario.

Thermal mass, ventilation, shading and shuttering are shown to have a large influence on summer peak temperatures with high thermal mass construction having a consistent beneficial effect for the range of scenarios studied.

Guidelines can have limitations in their applicability and can become obsolete and outdated. This study has demonstrated the role of simulation in informing design decisions. It is recommended that simulation is used in the design of sustainable housing and that a range of climates including predicted future climates [14] and occupancy and gains scenarios are considered.

## References

[1] THERMIE project BU/0127/97. www.cepheus.de

- [2] IEA, 2004, Solar heating and cooling, task28
- [3] HEEBPp, 2002, GIL72, Energy efficiency standards.
- [4] EEBPp, 1996, GIR53, Building a sustainable future.
- [5] HEEBPp, 2002, GIR89, BedZED, BRECSU.
- [6] HEEBPp, 2003, NPP119, Hockerton housing project
- [7] Vale B, Vale R, 2002, ISBN 0-500-28287-0
- [8] Pollard A et al, 1998, Heating energy and temperature in heavy mass houses. IPENZ Conf, Aukland NZ.
- [9] CIBSE, 2004, Guide F, Section4.2.2,p4-4.
- [10] Finney D, 2004, Buildings for a Future, spring edition, v13, no.4. Green Building Press
- [11] Mithraratne N, 2001, Phd Thesis, U of Aukland NZ.
- [12] Lazarus N, 2002, BedZED construction materials report part 1.DTI.
- [13] LaRoche P, Milne M, 2003, Effects of window size and thermal mass on building comfort. Solar Energy, Elsevier Press (accepted sept 03).
- [14] UKCIP Climate projections, http://www.ukcip.org.uk/scenarios/ukcip\_data/