

# Control of Overheating in Well-Insulated Housing

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## Summary

The longer-term insulation standards being considered as part of the on-going review of the Building Regulations may result in increased summer (or possibly 'shoulder' season) overheating and a consequent increase in the use of domestic air conditioning. In this project, the likely impacts of high insulation standards on overheating have been investigated and low carbon strategies for maintaining summer comfort have been developed.

The approach adopted has used dynamic thermal modelling to simulate the overheating performance of four house types. The extensive parametric study that is needed for the purpose of the project could only be achieved using advanced simulation techniques to develop an understanding of the critical performance parameters. An experimental screening design has been used for one of the house types to identify the relative importance of issues such as solar gain, thermal mass and ventilation in causing overheating. The findings of the first phase of the study have been developed in a further second series of simulation studies, for all four house types to provide more specific design guidance.

The second phase of simulation results have shown that overheating, both in degree hours above 27 °C and peak temperatures can be lessened by a range of realistic design options. By a combination of measures the number of degree hours above 27 °C can be reduced by almost 80%, and the internal temperature some 2.5 °C lower than the external air temperature

## Introduction

The longer-term future insulation standards being considered as part of the on-going review of the Building Regulations may result in increased summer (or possibly ‘shoulder’ season) overheating and a consequent increase in the use of domestic air conditioning. In this project, the likely impacts of high insulation standards <sup>(1)</sup> on overheating have been investigated and low carbon strategies for maintaining summer comfort have been developed. Table 1 shows the U-values assumed.

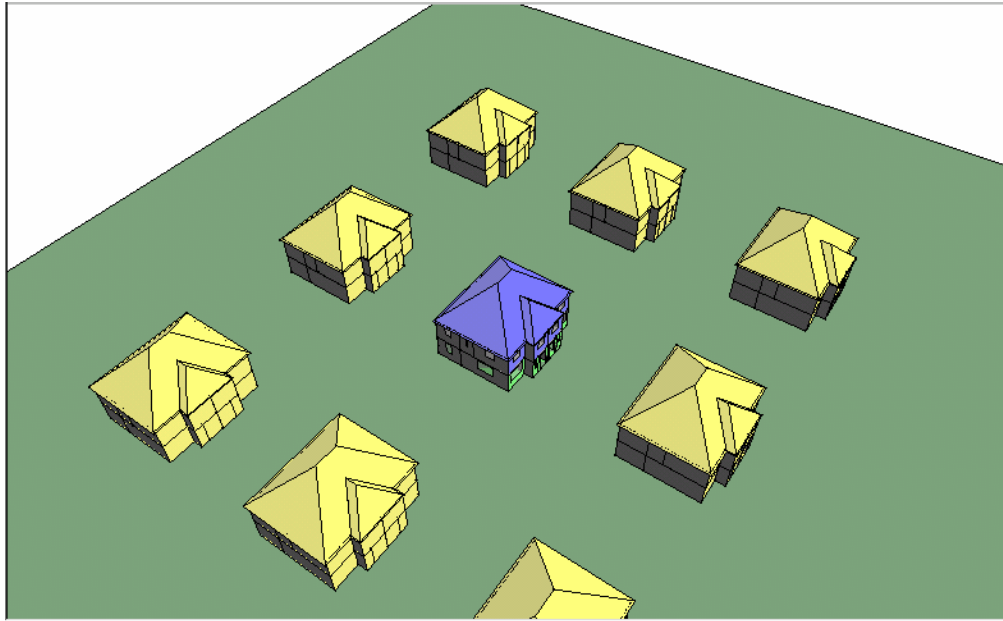
**Table 1: Proposed Future Elemental U-Values <sup>(1)</sup>.**

	W/m <sup>2</sup> ·K
walls	0.25
roofs	0.16
floors	0.22
windows, glazed outer doors and rooflights	1.3

The approach adopted has used advanced simulation techniques to develop an understanding of the critical performance parameters that influence the year-round performance of housing. The extensive parametric testing that is needed for the purpose of the project could only be achieved through dynamic thermal modelling. The project outputs have been geared towards developing technical specifications and design features for the construction industry to minimise potential overheating problems.

Four generic house types have been simulated: semi-detached, detached, top floor flat, and a town house. These house types were chosen to reflect an appropriate range of types and sizes of future housing both in floor area and construction. See Figure 1 for an example of a semi-detached house set in a development with 15% plan area density. (Plan area density is the density of buildings in the area surrounding the building of interest.)

The project had two phases. The first phase was a parametric simulation exercise in which the variable of concern was the number of degree-hours above 27 °C as predicted by the APACHE<sup>(2)</sup> thermal model. This established the ranking of the causes of the overheating. The second phase of the modelling focussed around the implementation of design measures based on the findings of the first phase rankings.



**Figure 1: Semi-detached house - 15% plan area density**

### **First Modelling Phase**

The aim of the first modelling phase of the project was to assess the relative importance of the different physical factors influencing possible overheating in housing. The following parameters were varied and the input parameter levels are shown:

1. *Plan area density*: 30% (e.g. typical for terrace rows), 15% (e.g. typical for detached / semi-detached), 0% (no close properties)
2. (Exterior) Solar protection: 80%, 40%, 0%
3. Percentage glazing in the most glazed façade (total glazing constant): 10%, 20%, 30%

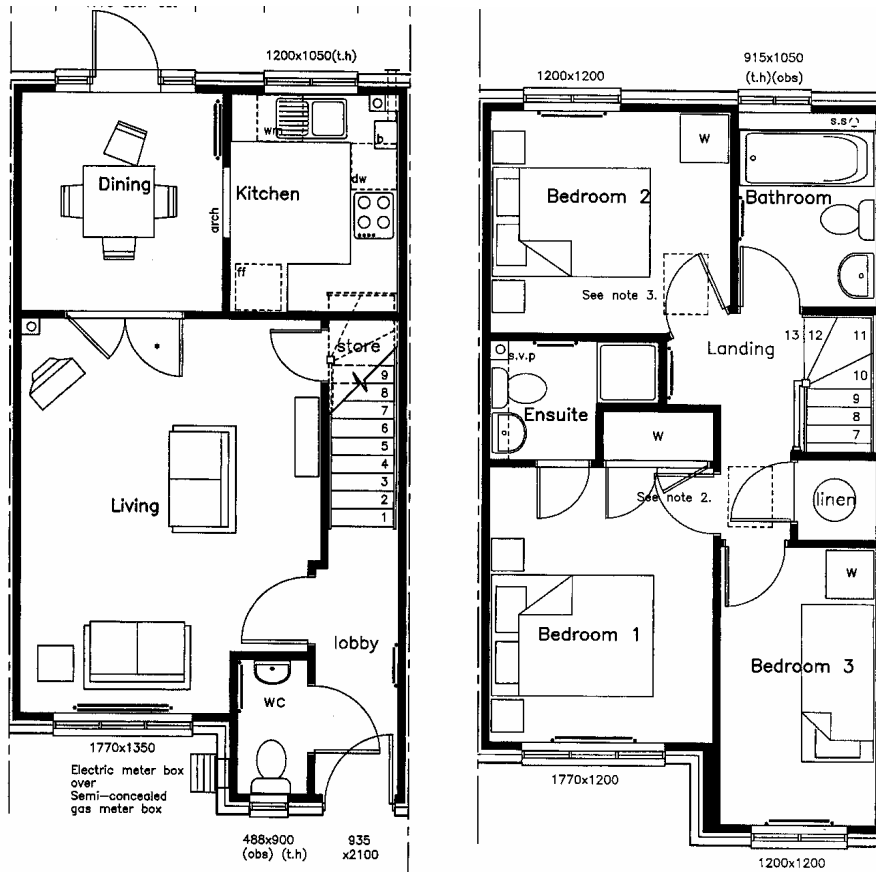
4. *Glazing transmittance* (total): triple glazing low E glass + clear float glass + low E glass (59%), double glazing both low E glass (66%), double glazing both clear float (76%)
5. Orientation of most glazed façade: East, South, West
6. *Thermal mass (admittance)*: high (5 W/m<sup>2</sup>·K), medium (3 W/m<sup>2</sup>·K), low (1 W/m<sup>2</sup>·K)
7. *Thermal insulation* (U-value): “2008”, “ADL 2002”, “ADL 1995”
8. *Number of occupants* (for internal heat gain): "1", "2.5", "4"
9. *Night cooling fan air*: delivery 6 ach, 3 ach, 0 ach
10. *Ventilation rate*: “high”, “medium”, “low”
11. *Roof albedo*: 0.7, 0.4, 0.1
12. *Heating demand profile*: "low", "medium", "high"

In the first analysis phase, regression analysis based on an experimental screening design<sup>(3)</sup> was used with a multiplicative power law model in which:

Predicted degree-hours above 27 °C =

$$a_0 \cdot (a_1^{\text{Plan\_area\_density}}) \cdot (a_2^{\text{Solar\_protection}}) \cdot (a_3^{\text{Glazing\_ratio}}) \cdot (a_4^{\text{Glazing\_transmittance}}) \cdot (a_5^{\text{Orientation}}) \cdot (a_6^{\text{Thermal\_mass}}) \cdot (a_7^{\text{Thermal\_insulation}}) \cdot (a_8^{\text{Internal\_heat\_gain}}) \cdot (a_9^{\text{Night\_cooling\_fan}}) \cdot (a_{10}^{\text{Ventilation\_rate}}) \cdot (a_{11}^{\text{Roof\_albedo}}) \cdot (a_{12}^{\text{Heating\_demand}})$$

where the  $a_i$ 's are found by linear regression on the logarithms of the results (responses) of the computational experiments. The exponents of the  $a_i$ 's are ‘coded variables’ and the exponents take values between –1 to +1 for each factor. The order of the levels of each input parameter has been arranged to anticipate the lowest to highest potential for overheating.



**Figure 2: Floor plans of semi-detached house.**

The results of the regression were used to screen the factors for their statistical significance.

The trends based on the multiplicative power law model are:

1. Plan area density is a significant factor for Bedroom 2 and a secondary factor for the Bathroom, otherwise it is not significant.
2. Solar protection is a significant factor for all rooms.
3. Glazing ratio is a significant factor for the Bathroom, Living Room and Dining room and a secondary factor for Bedroom 1 and the Lobby.
4. Glazing transmittance is significant in all rooms.
5. Orientation is a significant factor for the Dining room and the Kitchen, and a secondary factor for the Bathroom and Living room.
6. Thermal mass is significant in all rooms.

7. Thermal insulation is significant in all rooms, except Bedroom 3 in which it is a secondary factor.
8. Internal heat gain is significant for all rooms.
9. Night cooling fan is significant for all rooms except Bedrooms 1 and 3, for which it is a secondary factor.
10. Ventilation rate is a significant factor for all rooms.
11. Roof albedo is a significant factor for the Dining room and Kitchen, and a secondary factor for the Living room.
12. Heating demand is a significant factor for the Dining room and Kitchen.

In general, with respect to the ranges of the considered factors, the level of solar protection appears to have greatest influence on the overheating degree hours during the summer for certain rooms, while for others it is the ventilation rate that is of most importance. It should be noted that the experimental design method used was only intended to rank the factors in order of relative importance, and certain trivial anomalies were observed.

### **Second Modelling Phase**

In the second modelling phase, a set of simulation runs was conducted on the basis of the four key physical house characteristics that had been shown to influence overheating:

- thermal mass;
- solar gain;
- ventilation – modelled including feedback;
- incidental gains.

The intention of this second phase of the modelling was to establish design guidance for house builders and the construction industry. Consequently, the modelling strategy was

developed in two key ways to address this need. Firstly, physical aspects of the houses are determined by ‘real’ (typical) construction methods, e.g. thermal mass is derived from wall and floor constructions, and solar protection is related to a type of solar shading device. Secondly, in this phase of the modelling, ventilation rate was computed by the model rather than input as a schedule. This simulated natural ventilation more accurately as a function of internal and external temperatures differences and wind velocity. In addition window opening behaviour was modelled to respond to the internal temperature in the same way that occupants may intervene to prevent high temperatures through window opening.

For each of four representative house types, a Base Case was established:

- window opening triggered according to internal temperatures;
- U-values according to a proposed future standard (see Table 1);
- high transmission glazing (78%);
- lightweight construction (admittances in brackets) - insulated timber frame dry lined external walls with brick cladding ( $0.94 \text{ W/m}^2\cdot\text{K}$ ), suspended ground floor ( $1.6 \text{ W/m}^2\cdot\text{K}$ ) and upper floor ( $1.5 \text{ W/m}^2\cdot\text{K}$ ), stud internal partition walls ( $1.15 \text{ W/m}^2\cdot\text{K}$ );
- no night cooling;
- no solar shading;
- low roof albedo (0.1);
- flat and town house: 30% plan area density;  
semi- and detached houses: 15% plan area density;
- living room window oriented to south;
- glazing distributed according to original house plans;
- flat and semi-detached occupancy: “2.5 people”;  
detached and town houses occupancy: “4 people”.

Then, the effects of specific measures to counter possible overheating were examined. The details of these simulations are given in Table 2. Thus, a total of 25 annual simulations were performed during the second modelling phase.

**Table 2: Second modelling phase simulations**

	Town house	Detached house	Semi-detached house	Top floor corner flat	
Base Case	<b>Run A1</b>	<b>Run B1</b>	<b>Run C1</b>	<b>Run D1</b>	
Base Case + high thermal mass + night cooling by natural ventilation	<b>Run A2</b>	<b>Run B2</b>	<b>Run C2</b>	<b>Run D2</b>	
	<i>High thermal mass (admittances in brackets) ground (5.94 W/m<sup>2</sup>·K) and upper floor slabs with exposed ceiling slabs (5.88 W/m<sup>2</sup>·K), dry lined high mass internal (4.25 W/m<sup>2</sup>·K) and external walls (4.28 W/m<sup>2</sup>·K) Night cooling by natural ventilation fixed at 25% of openable window area</i>				
Base Case + solar shading	<b>Run A3</b>	<b>Run B3</b>	<b>Run C3</b>	<b>Run D3</b>	
	<i>Window overhangs</i>	<i>External louvres</i>	<i>Internal curtains</i>	<i>Window film</i>	
Base Case + reduced internal gains	<b>Run A4</b>	<b>Run B4</b>	<b>Run C4</b>	<b>Run D4</b>	
	<i>25% reduction in appliance, lighting and domestic hot water gains</i>				
Base Case + high thermal mass + night cooling by natural ventilation + solar shading + Reduced internal gains + high roof albedo	<b>Run A5</b>	<b>Run B5</b>	<b>Run C5</b>	<b>Run D5</b>	
Base Case + high roof albedo	<b>Run A6</b>	X		<b>Run D6</b>	
	<i>Albedo 0.7</i>			<i>Albedo 0.7</i>	
Base Case + whole house ventilation + high thermal mass + no window opening	X		<b>Run B6</b>	X	
			400 m <sup>3</sup> /h	<b>Run C6</b>	
			400 m <sup>3</sup> /h		

Base Case + whole house ventilation + high thermal mass			<b>Run C7</b>  400 m <sup>3</sup> /h	
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## Second Phase Results

The results presented here are the number of degree-hours above 27°C, and the percentage of the base case overheating, for the detached and semi-detached houses and can be seen in Tables 3 and 4.

**Table 3: Detached House - Overheating degree hours above 27 °C during the summer**

Run	Kitchen	% of Base	Master	% of Base	Living Room	% of Base
B1	615	100.0%	642	100.0%	476	100.0%
B2	284	46.2%	236	36.8%	209	43.9%
B3	403	65.5%	430	67.0%	310	65.1%
B4	561	91.2%	589	91.7%	440	92.4%
B5	155	25.2%	138	21.5%	111	23.3%
B6	7839	1275%	5783	900.8%	3260	684.9%

**Table 4: Semi-Detached House - Overheating degree hours above 27 °C during the summer**

Run	Bedroom 1	% of Base Case	Kitchen	% of Base Case	Living Room	% of Base Case
C1	831	100.0%	962	100.0%	486	100.0%
C2	240	28.9%	328	34.1%	201	41.4%
C3	747	89.9%	851	88.5%	441	90.7%
C4	707	85.1%	785	81.6%	443	91.2%
C5	186	22.4%	214	22.2%	166	34.2%
C6	2121	255.2%	7547	784.5%	3024	622.2%
C7	287	34.5%	460	47.8%	262	53.9%

Tables 5 and 6 rank each of the measures by room and show that Combined Measures (B5, C5) is the most effective for all rooms and Night Cooling (B2, C2) using natural ventilation

and thermal mass is the second most effective method. In the detached house, solar shading with external louvers (B3) consistently brings about greater reductions than a 25% reduction in appliance, lighting and domestic hot water gains (B4). In the semi-detached house, methods C3 and C4 bring about reductions that are more dependent on the room concerned. For example, in the north-facing kitchen, reduced internal gains are more significant than solar control. Constant balanced mechanical ventilation (at 400 m<sup>3</sup>/h for each whole house) with high thermal mass and without window opening is not able to remove sufficient excess heat from the space, and so results in more overheating than the Base Case for every room. A similar overall ranking in the results was obtained for the town house and the flat, except the absolute values of the overheating degree-hours were higher than for the semi- and detached houses.

**Table 5: Detached House - Ranking of overheating degree hours above 27 °C during the summer for the options by room**

	Least overheating ←————→ Most overheating					
Master Bedroom	B5	B2	B3	B4	B1	B6
Bedroom 2	B5	B2	B3	B4	B1	B6
Bedroom 3	B5	B2	B3	B4	B1	B6
Bedroom 4	B5	B2	B3	B4	B1	B6
Bathroom	B5	B2	B3	B4	B1	B6
Dining	B5	B2	B3	B4	B1	B6
Hall	B5	B2	B3	B4	B1	B6
Kitchen	B5	B2	B3	B4	B1	B6
Landing	B5	B2	B3	B4	B1	B6
Living	B5	B2	B3	B4	B1	B6
Ensuite	B5	B2	B3	B4	B1	B6
WC	B5	B2	B3	B4	B1	B6

**Table 6: Semi-Detached House - Ranking of overheating degree hours above 27 °C during the summer for the options by room**

	Least overheating ←————→ Most overheating					
Bedroom 1	C5	C2	C4	C3	C1	C6

Bedroom 2	C5	C2	C3	C4	C1	C6
Bedroom 3	C5	C2	C3	C4	C1	C6
Bathroom	C5	C2	C3	C4	C1	C6
Dining room	C5	C2	C3	C4	C1	C6
Kitchen	C5	C2	C4	C3	C1	C6
Lobby	C5	C2	C4	C3	C1	C6
Landing	C5	C2	C4	C3	C1	C6
Living room	C5	C2	C3	C4	C1	C6
Ensuite	C5	C2	C4	C3	C1	C6

## Conclusions

Within the definition of overheating used in this study, none of the measures considered will eliminate overheating entirely in dwellings insulated to a certain proposed future performance standard. However, employing a combination of measures would reduce overheating to a level less than that of an equivalent dwelling constructed to 2002 Building Regulations.

The simulation results have shown that overheating, both in degree hours above 27 °C and peak temperatures can be lessened by a range of realistic design options. By a combination of measures the number of degree hours above 27 °C can be reduced by almost 80%, and the internal temperature some 2.5°C lower than the external air temperature.

Balanced mechanical ventilation at levels appropriate for the maintenance of good indoor air quality is not able to mitigate overheating in dwellings with high thermal mass. Whole house mechanical ventilation in a thermally heavy weight building with the normal design flow rates for hygienic ventilation is not able to remove sufficient heat to prevent the overheating of the house during the daytime.

It has been demonstrated that energy efficient houses are possible that combine low annual heating demand with high summertime performance. Night-time cooling of the thermal mass is most effective in preventing building overheating. This work does not necessarily preclude

thermally lightweight, highly insulated housing, for which attention should be given to providing occupants with good solar control in combination with low internal gains. Also, in practice, the thermal mass of lightweight construction is usually increased by internal fittings and furniture due to its large surface area. Therefore it is likely that natural night cooling would be beneficial for all housing types, although most effective in thermally heavyweight construction.

### **References**

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