



## **Thermal Mass and the EPBD**

### **SEI draft action plan - response by the concrete industry**

Irish Concrete Federation  
July 2005

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# 1 Executive summary

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This study has identified the importance that thermal mass has on the heating energy consumption and internal comfort in dwellings and why it should be taken into account when implementing the Energy performance in Buildings Directive.

This study has concluded that:

- By accounting for thermal mass in dwelling fabric construction savings between 5 and 9% of heating energy consumption could be realised if a thermally heavyweight fabric is incorporated. Therefore it is important that the effect thermal mass is incorporated into the assessment of dwelling energy consumption.
- It is important to test for overheating in dwellings to minimise the likelihood of retrofit air conditioning. It is also important to ensure that the effect of thermal mass is correctly accounted for when assessing overheating.
- It is important to take account of the energy consumption of any air conditioning system installed so as to accurately represent the overall energy consumption in dwellings.

Simple and more complex methods for accounting for the above factors have been proposed in section 5 of this report, including suggested parametric values necessary.

It is recommended that:

- A fabric admittance factor is included in the heating energy consumption calculation
- A test is made for overheating which contains a fabric admittance factor
- Cooling system energy consumption calculation with a fabric admittance factor is included in the dwelling energy consumption rating

This study has also shown that calculation methods established or proposed for other member states may not necessarily be representative of all dwelling types, and that modification of these methods may be necessary.

## 2 Introduction

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The objective of this study was to identify the importance thermal mass has on the heating energy consumption and internal comfort in dwellings and why it should be taken into account when implementing the Energy Performance in Buildings Directive. Specifically the objectives are to:

- Comment on the influence if any that current EU member states regulations have on the thermal mass of dwellings
- Comment on the influence if any that proposed EU member states regulations have on the thermal mass of dwellings
- Identify the effect that thermal mass has on energy consumption (carbon dioxide emissions) and why it should be taken account of in the calculations for compliance with the EPBD and future building regulations.
- Identify a simple methodology to account for the benefits of thermal mass in the carbon dioxide emissions rating for dwellings.

The effect of thermal mass has been calculated, measured by heating energy consumption and comfort temperature comparison, using IES<sup>(1)</sup> dynamic thermal modelling software for a range of typical dwelling types:

- Apartments with average glazing areas
- Apartments with high glazing areas
- 3 bed Semi detached dwelling
- 4 bed Detached dwelling

These results have been compared with selected output from proposed EU member states regulations, and a simple methodology to account for the effect thermal mass has on energy consumption and carbon dioxide emissions has been proposed.

## 3 Current and proposed EU building codes

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Throughout the EU the existing building codes require upgrading and in some cases are being replaced in order to incorporate all of the elements of the Energy Performance in Buildings Directive (EPBD). As the current Irish regulations are similar to that for the UK, comparison with current and proposed UK building codes have been made. Cross reference is also made to the current German building codes.

### 3.1 Current building codes

For dwellings to demonstrate compliance with the current Part L of the UK building regulations, three methods can be applied.

- Elemental Method
- Target U-value Method
- Carbon Index Method (based on the Standard Assessment Procedure, 2001 (SAP2001))

Only the Carbon Index Method looks at the interaction of the building with the heating system albeit in a simplistic way. Thermal performance is assessed by the U-value only and no account is taken of the heat storing properties of the fabric.

The current German building codes do however take account of heat storing properties of the building fabric in a simplistic way and gives the assessor the choice of allowing default values for lightweight or heavyweight fabric, or a detailed calculation method to be used.

### 3.2 Proposed UK building codes

The UK proposal to comply with the EPBD is to update Part L of the building regulations for dwellings. This allows only a modified Carbon Index method, that calculates a Carbon Dioxide Emission Rating for a dwelling in accordance with a new Standard Assessment Procedure, SAP(2005) <sup>(2)</sup>. This procedure is currently being developed by BRE and is available in draft. For buildings other than dwellings, a separate code is being developed based on the Dutch standard NEN 2916, as reviewed by Hitchin <sup>(3)</sup>, modified to include all of the necessary elements of the EPBD.

It should be noted that the UK has chosen to rate buildings by their carbon dioxide emissions and not their energy consumption. The reason for this is that the carbon dioxide emissions take account of the efficiency of electricity generation that would otherwise not be accounted for. For example electric heating is 100% efficient in the dwelling and uses less kWh, whilst gas heating is 80% efficient in the dwelling and used more kWh. However the cost and emissions associated with electric heating are significantly greater than that for gas if generation and distribution systems are accounted for.

### 3.2.1 Thermal mass

The UK's proposed draft SAP(2005) rating is not influenced by the thermal mass of the building fabric. There is however a separate overheating assessment within SAP(2005) appendix P of the document that takes data from the SAP(2005) spreadsheet to predict the average summer temperature of the dwelling. The calculation accounts for:

- The external air temperature in the building location
- The heat loss through the fabric and ventilation
- The heat gain from internal and solar loads
- The thermal mass of the building

In the procedure, the average summer temperature within the dwelling is adjusted to take account of the thermal mass of the dwelling fabric calculated from the area weighted admittance factor of the dwelling. The maximum adjustment possible proposed in the draft SAP(2005) is a decrease of 1°C. The accuracy of this adjustment is discussed in section 4.

### 3.2.2 Air conditioning

The use of air conditioning to offset overheating in dwellings is not yet widespread. Because dwellings are now more highly insulated, generally lined internally with plasterboard (thermally lightweight), and often have large areas of glazing, the use of air conditioning in dwellings is expected to increase. It is therefore important that the energy use associated with air conditioning is taken account for in dwelling energy rating to promote energy efficient design.

Air conditioning carbon dioxide emissions has not been accounted for in the UK's draft SAP(2005), although there are plans for it to be taken account of in the next revision of the UK's building regulations part L in 2010.

The data contained in SAP(2005) could be used to predict the energy use associated with air conditioning, as is currently done with the Ecohomes assessment<sup>(4)</sup>. This assessment method, developed by the BRE, rates the sustainability of dwellings in terms of their construction, energy use, transport and other aspects. The energy use section is relevant to achieving compliance with the EPBD.

The energy use section of the Ecohomes assessment utilises the output from SAP(2001) to predict the carbon dioxide emissions of dwellings including lighting, air conditioning and renewable energy technologies which are not accounted for in SAP(2001). The carbon dioxide emissions of air conditioning is calculated using:

- The seasonal coefficient of performance (COP) of the air conditioning and how it is controlled
- How much of the dwelling is air conditioned
- The external climate (using cooling degree days)

No account is taken of the gains from solar and internal loads, dwelling thermal mass which would reduce how often the air conditioning is used and the amount of cooling necessary.

## 4 Accounting for the benefits of thermal mass in dwellings

### 4.1 Apartments

A typical 70m<sup>2</sup> two bedroom apartment has been modelled; see *Figure 1*, the details of which are contained in section 7.

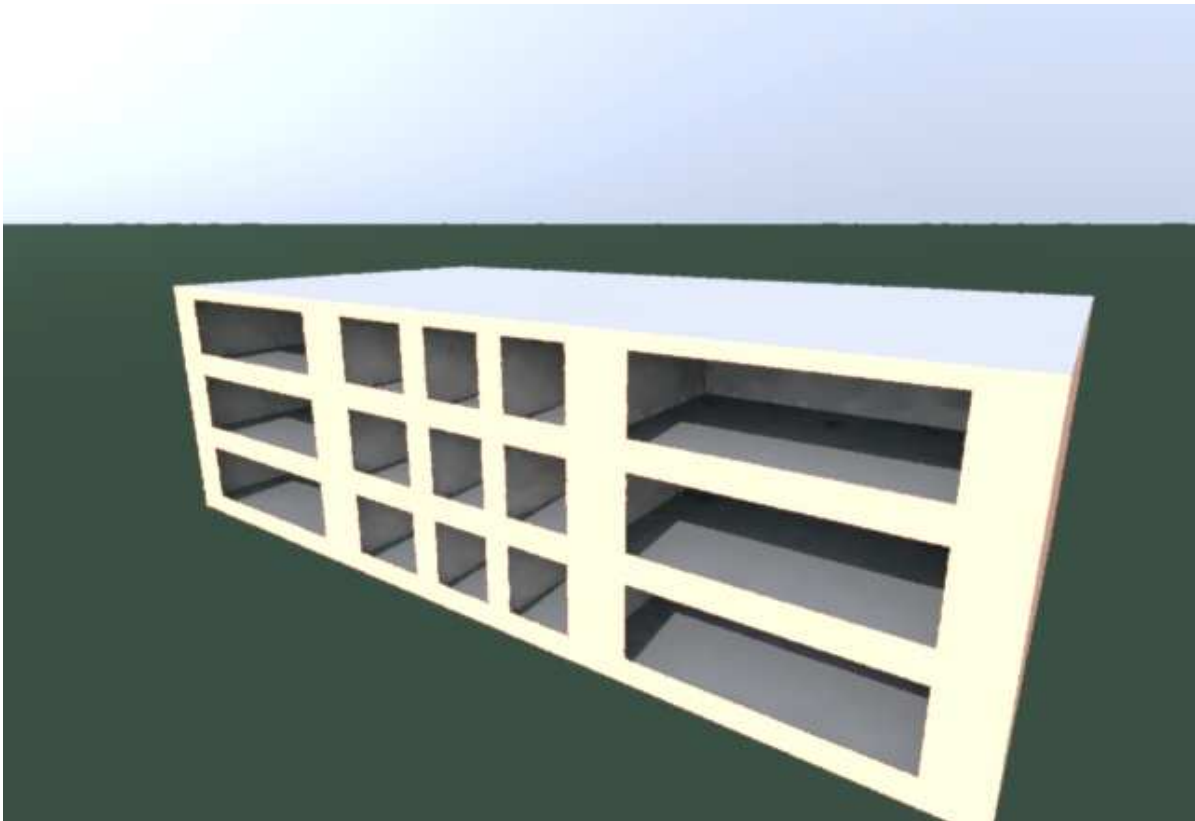
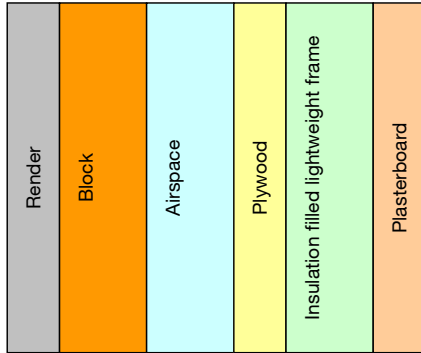


Figure 1 **Typical apartment block (glazing 20% of the floor area)**

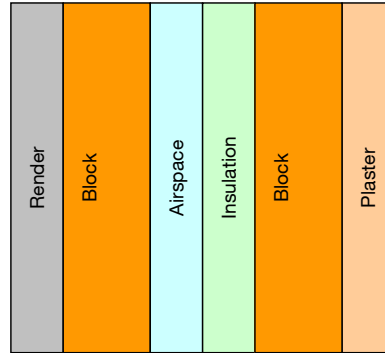
Two scenarios were investigated:

- Minimum glazing (area approximately 20% of the dwelling floor area)
- Maximum glazing (area approximately 54% of the dwelling floor area)

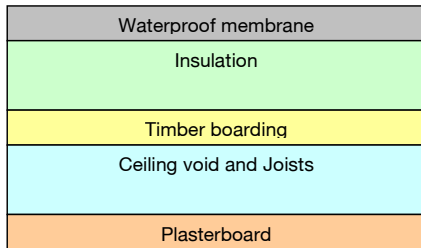
The lightweight and heavyweight construction assumed for the model is summarised in *Figure 2* below, full technical details of which are given in section 7.1. These constructions were taken as the two extremes of lightweight and heavyweight construction. Actual constructions are likely to be somewhere between the two.



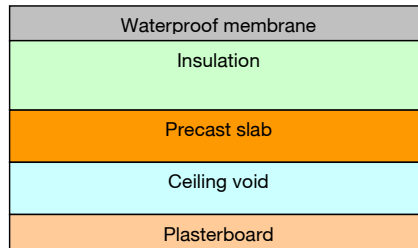
Wall construction Lightweight Model



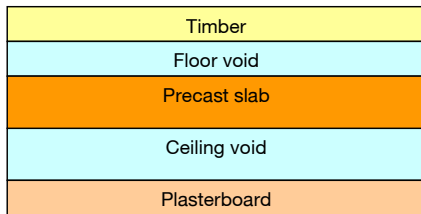
Wall construction Heavyweight Model



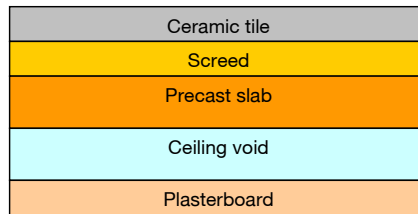
Roof construction lightweight model



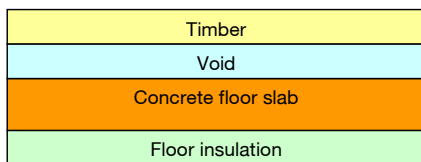
Roof construction heavyweight model



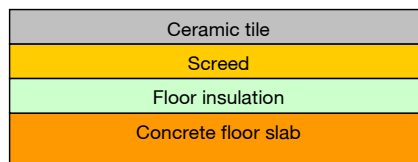
Intermediate floor lightweight model



Intermediate floor heavyweight model



Ground floor lightweight model



Ground floor heavyweight model

Figure 2 Apartment building fabric constructions assumed

#### 4.1.1 Energy consumption comparison

The predicted energy consumption of a typical apartment on the ground, intermediate and top floors has been investigated. The energy consumption predicted for each floor is the mean of a North and South facing apartment. The overall mean energy consumption over all floors has been indicated that is representative of an apartment block. The following table shows the energy consumption comparison.

Heating energy consumption	Minimum glazing area 20% of the floor area		Maximum glazing area 54% of the floor area	
	Lightweight	Heavyweight	Lightweight	Heavyweight
Construction	Lightweight	Heavyweight	Lightweight	Heavyweight
Lower floor	824 kWh	761 kWh	1381 kWh	1381 kWh
Mid floors	621 kWh	572 kWh	1257 kWh	1180 kWh
Top floor	984 kWh	884 kWh	1726 kWh	1505 kWh
Average	807 kWh (11.5 kWh/m <sup>2</sup> )	738 kWh (10.5 kWh/m <sup>2</sup> )	1493 kWh (21.3 kWh/m <sup>2</sup> )	1355 kWh (19.4 kWh/m <sup>2</sup> )

Table 1 Apartment heating energy consumption prediction

It was found that on average there was an 8 to 13% (mean 9%) reduction in heating energy consumption when a heavyweight fabric was utilised. The largest difference was the highly glazed top floor apartment where the major difference between lightweight and heavyweight constructions was with the ceiling inclusion of a concrete roof slab.

#### 4.1.2 Temperature comparison

The thermal mass of the dwelling fabric acts as a heat store. *Figure 3* and *Figure 4* on the following page illustrate this by comparing the air and resultant temperature in the mid floor South facing lounge of the apartment on a cold winter's day.

The temperature in the dwelling decayed when the heating was switched off during the night. This temperature decay was approximately 1°C less for the heavyweight apartment than that the corresponding lightweight apartment. The temperature decay during the day was influenced by solar gain resulting in an increase in room temperature. The increase was larger for the lightweight apartment and was in proportion to the glazing area.

Heavyweight fabric was shown to reduce change in internal temperature as a result of fabric heat storage and solar heat gain.

The performance of the dwelling fabric thermal mass in summer is illustrated in *Figure 5* and *Figure 6* on the following pages.

The rise in internal temperature as a result of solar and internal gains was shown to be 0.75°C less for the heavyweight dwelling than the corresponding lightweight dwelling irrespective of glazing area. This shows the passive cooling of the dwelling fabric in action. The actual peak temperature increased as the area of glazing was increased.

Again the heavyweight fabric was shown to reduce the change in internal temperature as a result of fabric heat storage and solar heat gain.

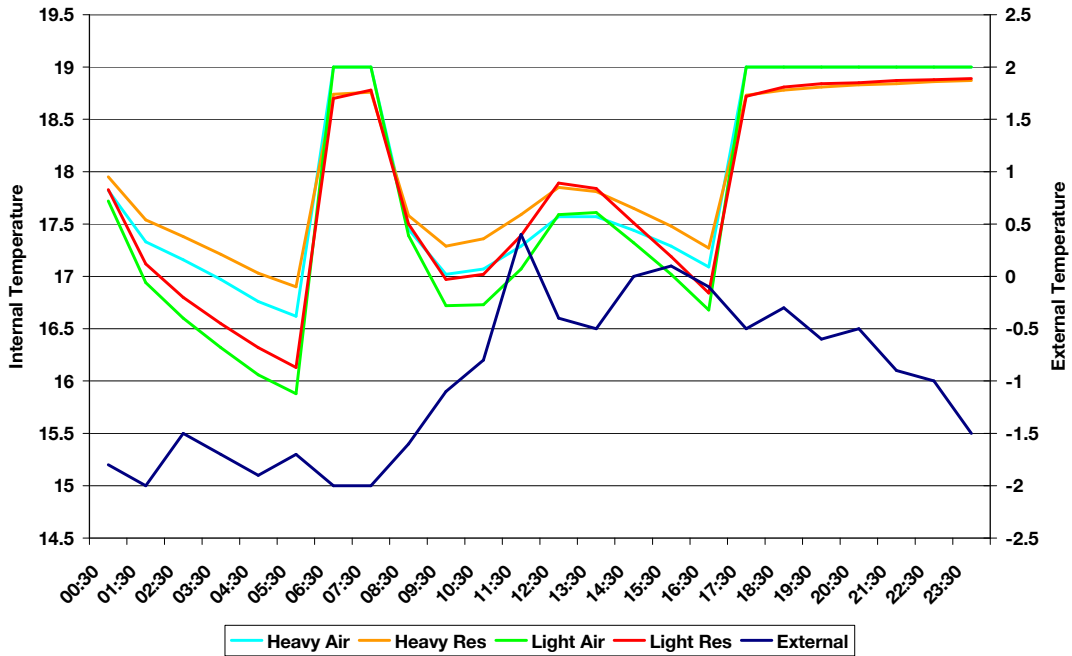


Figure 3 Mid floor South facing apartment 20% glazing lounge cold winter day temperature

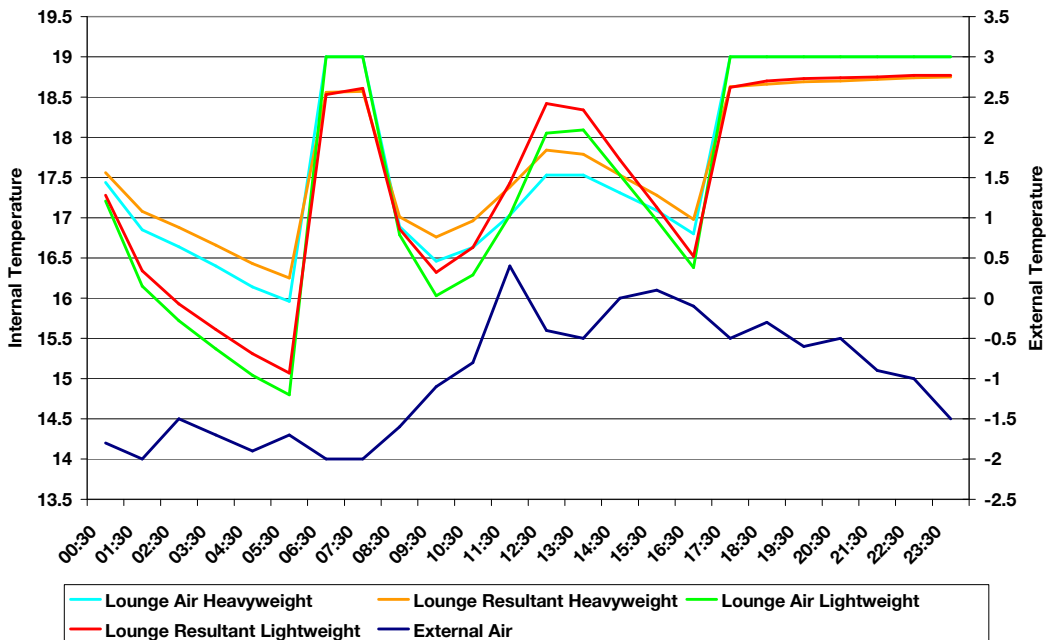


Figure 4 Mid floor South facing apartment 54% glazing lounge cold winter day temperature

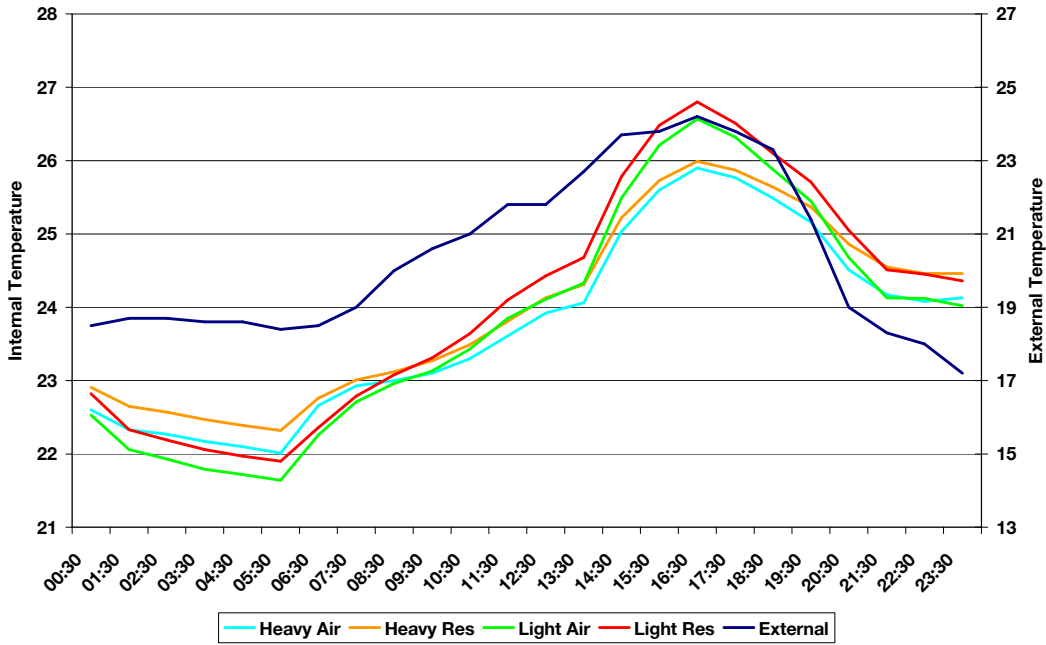


Figure 5 Mid floor South facing apartment 20% glazing lounge hot summer day temperature

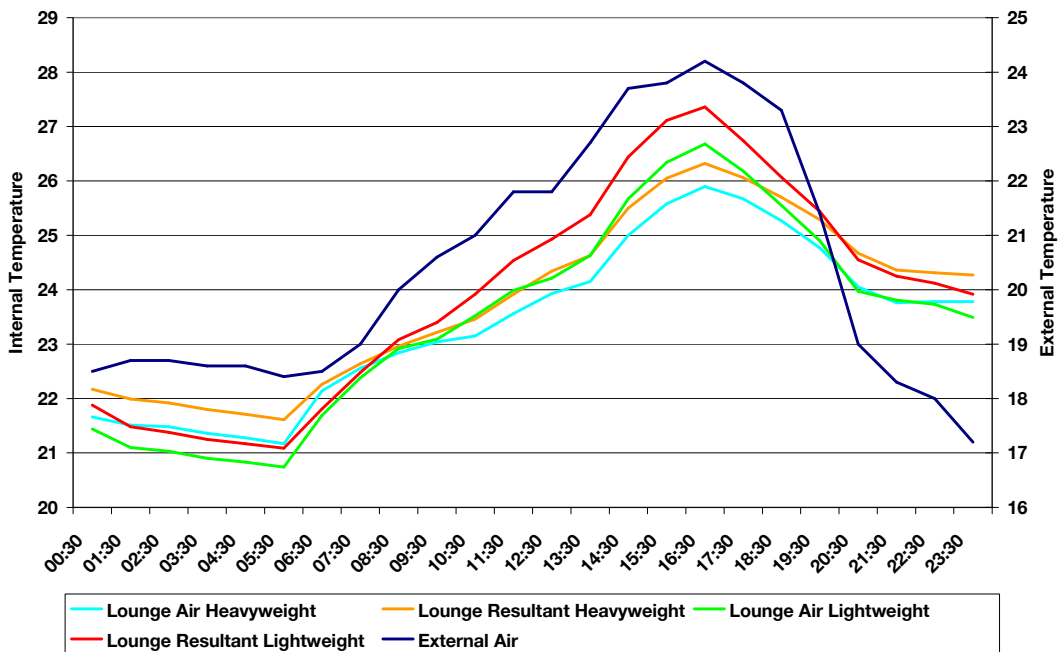


Figure 6 Top floor South facing apartment 54% glazing lounge hot summer day temperature

#### 4.1.3 SAP overheating assessment comparison

The summer temperature predictions have been compared with the proposed UK's SAP appendix P overheating assessment as follows:

Dwelling	Area weighted admittance (YA)	SAP appendix P increased mean internal temperature (°C)	Dynamic thermal model increased mean internal temperature (°C)
Lightweight apartment 20% glazed	637	0.18	0.5 – 1.0
Heavyweight apartment 20% glazed	1020	0	0
Lightweight apartment 54% glazed	623	0.23	0.5 – 1.0
Heavyweight apartment 54% glazed	957	0	0

Table 2 **Apartment overheating assessment comparison**

It can be seen that the current proposal for the UK's overheating assessment does not necessarily take full account of the benefit fabric thermal mass brings to reducing overheating for the apartments.

#### 4.2 Semi detached dwellings

A typical 90m<sup>2</sup> three bedroom semi detached dwelling has been modelled; see *Figure 7*, the details of which are contained in section 7.



Figure 7 **Typical semi detached dwelling**

Window area in this instance has been taken as 15% of the floor area.

The lightweight and heavyweight construction assumed for the model is summarised in *Figure 8* below, full technical details of which are given in section 7.1. These constructions were taken as the two extremes of lightweight and heavyweight construction for semi detached dwellings. Actual constructions are likely to be somewhere between the two.

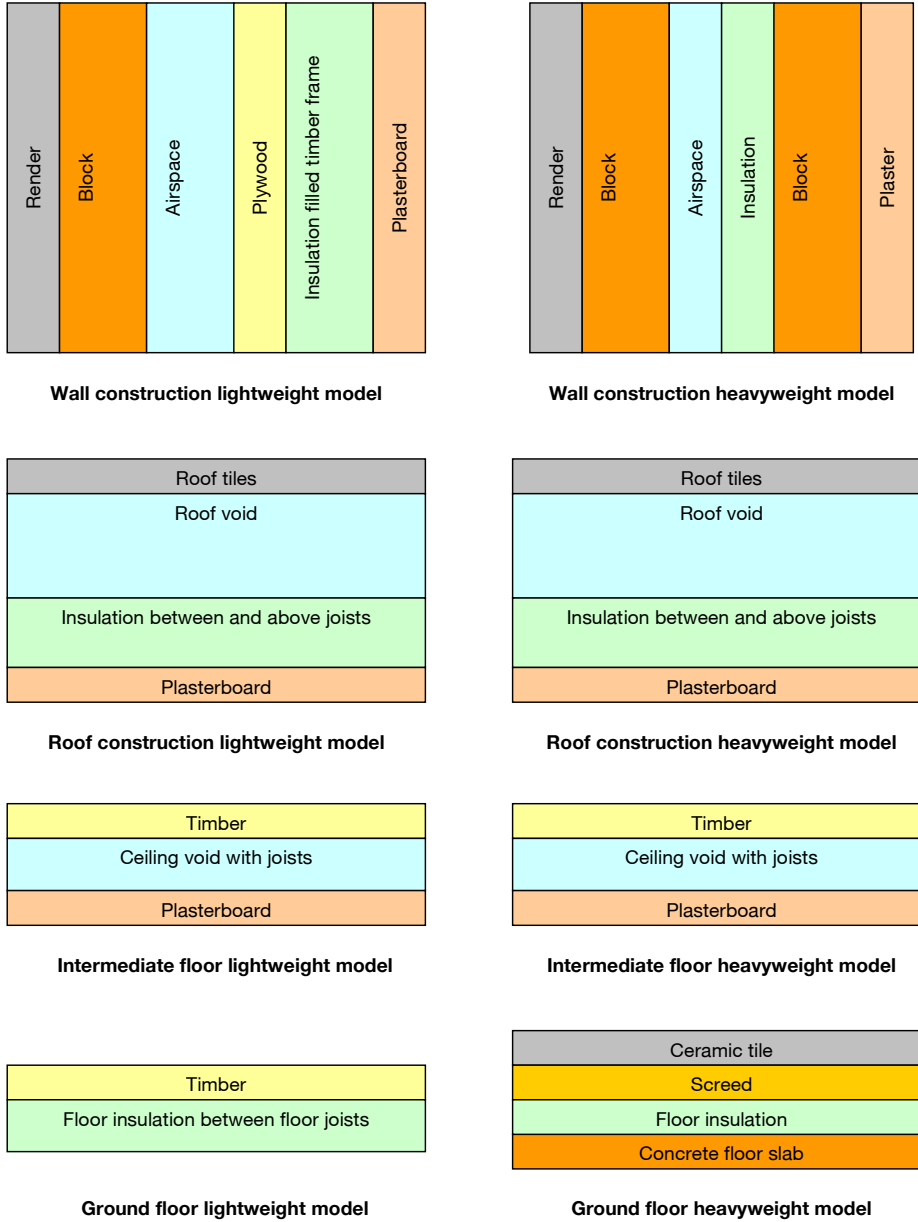


Figure 8 Semi detached dwelling fabric constructions assumed

#### 4.2.1 Energy consumption comparison

A single semi detached dwelling has been modelled with the party wall to the adjoining dwelling was to the West. The following table shows the predicted heating energy demand.

Construction type	Lightweight	Heavyweight
Semi detached dwelling	2138 kWh (23.8 kWh/m <sup>2</sup> )	2036 kWh (22.6 kWh/m <sup>2</sup> )

Table 3 Semi detached dwelling heating energy consumption

It was found that on average there was a 5% reduction in heating energy demand when a heavyweight fabric was utilised. The difference in heating energy demand was of a similar order of magnitude as that for the apartments. The main difference was that the fabric for the dwelling is more lightweight with the use of timber floor and roof construction. The energy consumption is likely to reduce further should a concrete floor construction be used for the first floor.

#### 4.2.2 Temperature comparison

The thermal mass of the dwelling fabric acts as a heat store. *Figure 9* on the following page illustrate this by comparing the air and resultant temperature in the lounge of the semi detached dwelling for a cold winter's day.

The temperature decayed when the heating was switched off during the night. This temperature decay was approximately 1°C less for the heavyweight dwelling than that the corresponding lightweight dwelling. The temperature decay during the day was reduced because of the solar gain through glazing. This gain was less than for the apartments because of the smaller proportion of glazing within the external walls. Heavyweight fabric was shown to reduce change in internal temperature as a result of fabric heat storage and solar heat gain.

The performance of the dwelling fabric thermal mass in summer is illustrated in *Figure 10* on the following page.

The rise in internal temperature as a result of solar and internal gains was shown to be 1°C less for the heavyweight dwelling than the corresponding lightweight dwelling. This shows the passive cooling of the dwelling fabric in action. Again the heavyweight fabric was shown to reduce the change in internal temperature as a result of fabric heat storage and solar heat gain. The temperature swing is likely to reduce further should a concrete floor construction be used for the first floor.

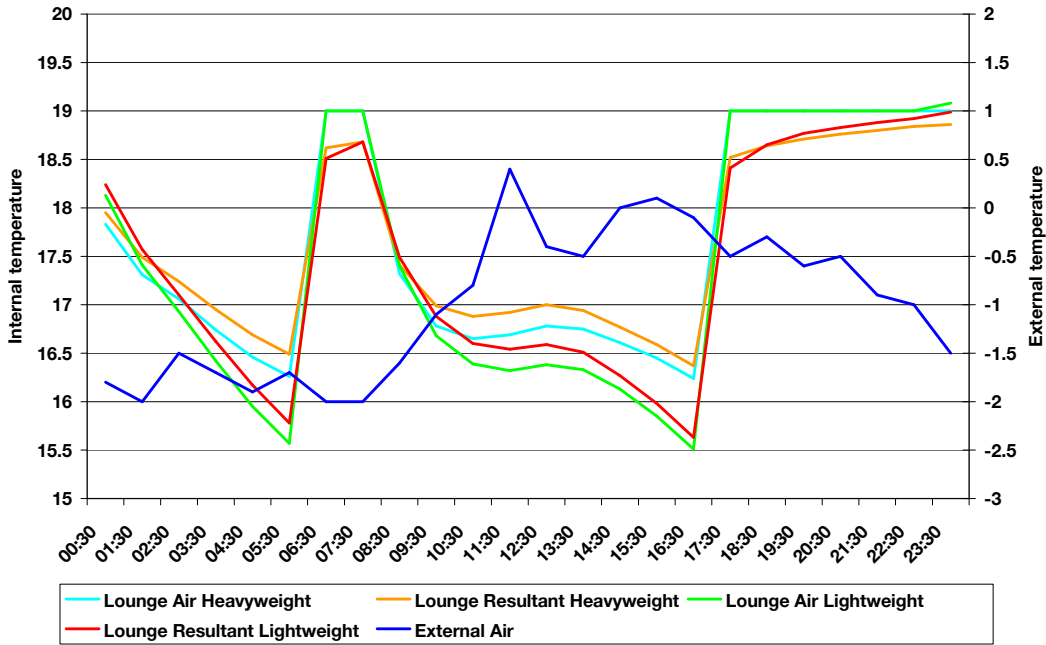


Figure 9 Semi detached dwelling lounge winter day temperature

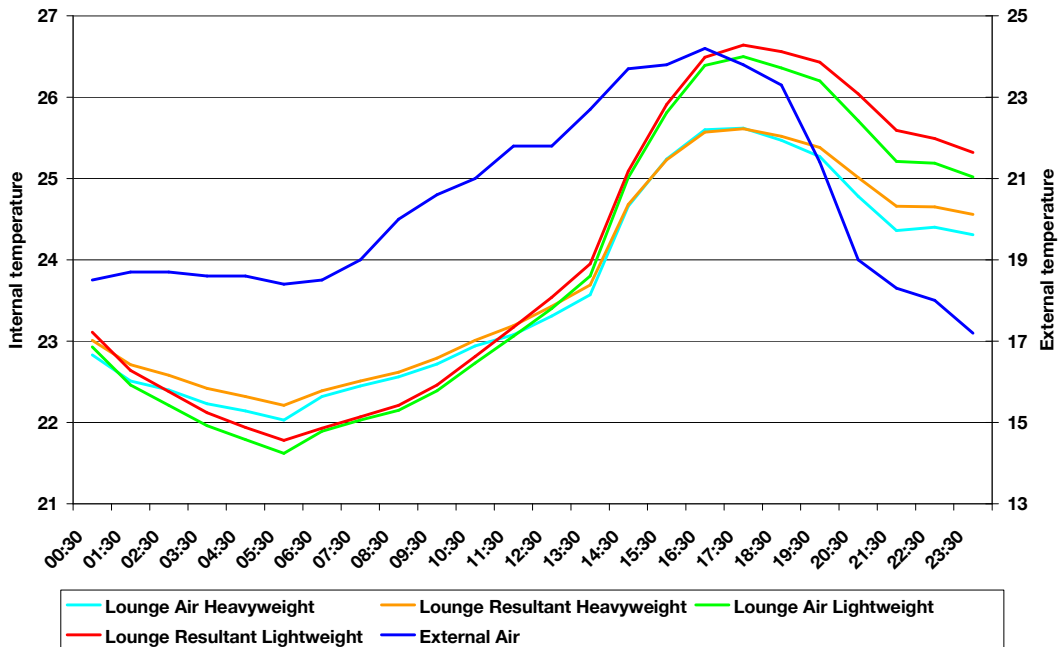


Figure 10 Semi detached dwelling lounge hot summer day temperature

#### 4.2.3 SAP overheating assessment comparison

The summer temperature predictions have been compared with the proposed UK's SAP appendix P overheating assessment as follows:

<b>Dwelling</b>	<b>Area weighted admittance (YA)</b>	<b>SAP appendix P increased mean internal temperature (°C)</b>	<b>DTM increased mean internal temperature (°C)</b>
Lightweight dwelling	522	0.91	0.75 – 1.5
Heavyweight dwelling	1246	0	0

Table 4 **Semi detached dwelling overheating assessment comparison**

It can be seen that the current proposal for the UK's overheating assessment does in this instance takes full account of the benefit fabric thermal mass brings to reducing overheating for the semi detached dwellings.

### 4.3 Detached dwellings

A typical 165m<sup>2</sup> four bedroom detached dwelling has been modelled; see *Figure 11*, the details of which are contained in section 7.



Figure 11 **Typical detached dwelling model**

Window area in this instance has been taken as 20% of the floor area.

The lightweight and heavyweight construction assumed for the model was as those for the semi detached dwelling, see *Figure 8* above. These constructions were taken as the two extremes of lightweight and heavyweight construction for semi detached dwellings. Actual constructions are likely to be somewhere between the two.

#### 4.3.1 Energy consumption comparison

The following table shows the predicted heating energy demand.

Construction type	Lightweight	Heavyweight
Detached dwelling	3861 kWh (23.4 kWh/m <sup>2</sup> )	3646 kWh (22.1 kWh/m <sup>2</sup> )

Table 5 **Detached dwelling heating energy consumption comparison**

It was found that on average there was a 6% reduction in heating energy demand when a heavyweight fabric was utilised, similar to that for the semi detached dwelling. The energy consumption is likely to reduce further should a concrete floor construction be used for the first floor.

#### 4.3.2 Temperature comparison

The thermal mass of the dwelling fabric acts as a heat store. *Figure 12* on the following page illustrate this by comparing the air and resultant temperature in the lounge of the detached dwelling for a cold winter's day.

The temperature decayed when the heating was switched off during the night. This temperature decay was approximately 2°C less for the heavyweight dwelling than that the corresponding lightweight dwelling. The temperature decay during the day was reduced because of the solar gain through glazing. This was similar to that for the semi detached dwelling. Heavyweight fabric was shown to reduce change in internal temperature as a result of fabric heat storage and solar heat gain.

The performance of the dwelling fabric thermal mass in summer is illustrated in *Figure 13* on the following page.

The rise in internal temperature as a result of solar and internal gains was shown to be 1.5°C less for the heavyweight dwelling than the corresponding lightweight dwelling. This shows the passive cooling of the dwelling fabric in action. Again the heavyweight fabric was shown to reduce the change in internal temperature as a result of fabric heat storage and solar heat gain. The temperature swing is likely to reduce further should a concrete floor construction be used for the first floor.

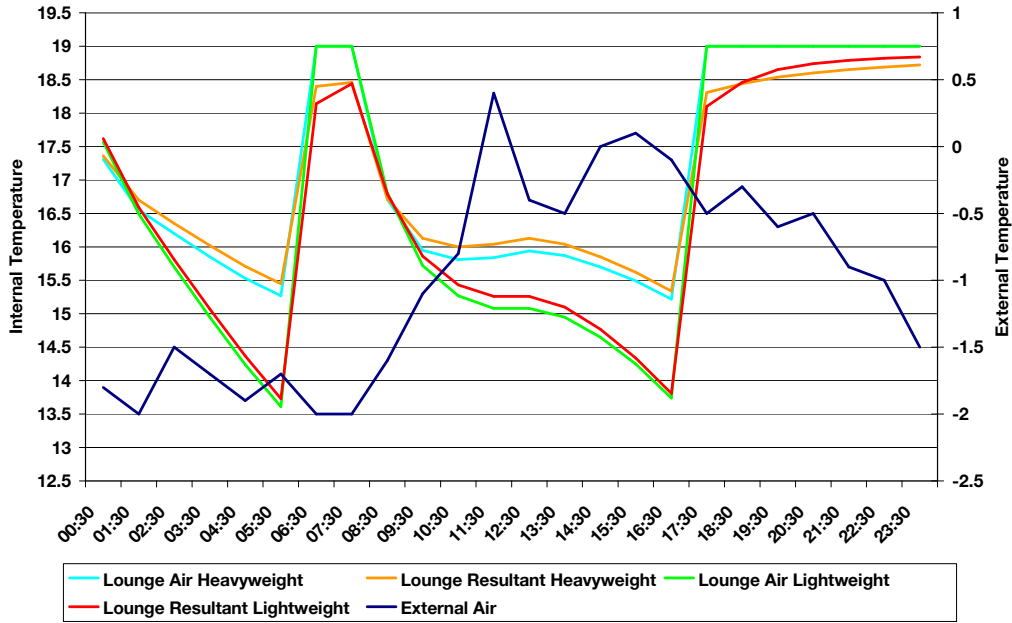


Figure 12 Detached dwelling lounge winter day temperature

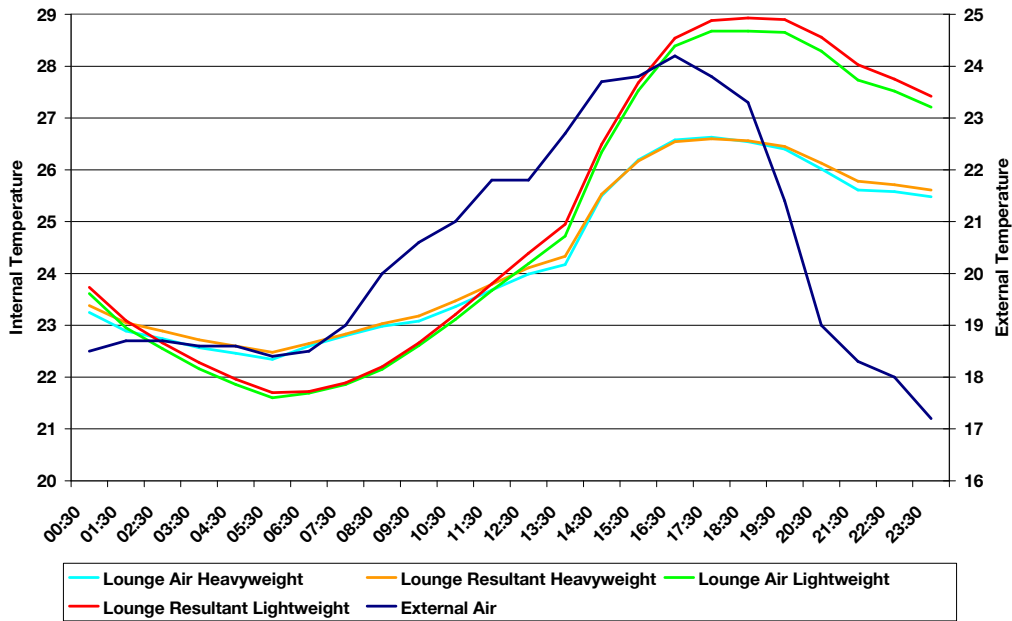


Figure 13 Detached dwelling lounge hot summer day temperature

#### 4.3.3 SAP overheating assessment comparison

The summer temperature predictions have been compared with the proposed UK's SAP appendix P overheating assessment as follows:

Dwelling	Area weighted admittance (YA)	SAP appendix P increased mean internal temperature (°C)	DTM increased mean internal temperature (°C)
Lightweight dwelling	884	0.67	1 – 2
Heavyweight dwelling	2399	0	0

Table 6 Detached dwelling overheating assessment comparison

It can be seen that the current proposal for the UK's overheating assessment does not necessarily take full account of the benefit fabric thermal mass brings to reducing overheating for the dwelling.

## 5 Proposals

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In order to achieve the overall aim of the EPBD and reduce the energy consumption (or carbon dioxide emissions) in buildings it is important to realistically account for all sources of energy consumption in buildings. Detailed assessment of building energy consumption is usually achieved using dynamic thermal modelling software. As this software is currently used only in relatively complex or prestigious buildings, there is a need to have a simplified calculation method that can be easily applied to the smallest and simplest buildings, particularly dwellings.

The UK's SAP(2005) could be adopted by Ireland to provide energy ratings for dwellings. There are however a number of simplifications made in this method that may need modification to accurately reflect the energy consumption of all dwelling types.

If SAP(2005) is adopted the following proposals are made to achieve a more realistic simplified energy rating method for dwellings.

### 5.1 Heating energy consumption

From this study, we have shown that there could be on average between 4 and 9% reduction in heating system carbon dioxide emissions achieved by incorporating thermally heavyweight building fabric in dwellings with identical average area weighted U-value. We therefore propose that this is accounted for by incorporating a building fabric admittance factor. Options for identifying what this factor should be are:

- Provide admittance factors for standard building construction types
- Calculating the admittance factor from the area weighted admittance of the dwelling fabric in a similar way to the proposed SAP(2005) appendix P overheating assessment, see section 5.2.
- Utilise dynamic thermal modelling to calculate the heating energy consumption of the dwelling

The first and second options are the most simple, the second being the most flexible in terms of accounting for all possible construction types.

It is important that the admittance factor is calibrated to ensure a realistic value is incorporated. Incorporating this feature will be similar to that currently in the German regulations and goes beyond that proposed for the UK's regulations for dwellings.

## 5.2 Summer overheating

It is important to test for overheating to minimise the need for the installation of retrofit air conditioning to resolve issues of discomfort in dwellings. As thermal mass of the dwelling fabric has a significant influence on the degree of overheating, a thermal mass factor should be incorporated into the calculation.

It is proposed that the UK's SAP(2005) appendix P overheating assessment that calculates the mean summer temperature within a dwelling to rate the likelihood of high internal temperature during hot weather is adopted.

This calculation takes account of:

- solar gains through windows (including solar shading provision)
- Fabric and ventilation losses
- Internal heat gains
- The mean external temperature of the building location
- Thermal mass of the building

We have shown that the thermal mass factor does not represent all dwelling types because it is limited to a maximum 1°C temperature reduction. From the limited selection of dwelling types tested, our study has shown that there is often a larger reduction in summer temperature with some building types, it is important that this factor is reviewed and a value representative of all dwelling types incorporated. We suggest that 2°C should be used as a realistic value.

## 5.3 Air conditioning energy consumption

It is important to ensure that when air conditioning is installed, the energy consumption associated with it are taken into account and that where necessary other elements that reduce energy consumption are incorporated to offset them.

The energy consumption of air conditioning will be dependant on the thermal mass of the dwelling fabric and an admittance factor, similar to that proposed for SAP(2005) appendix P, should be incorporated into any calculation methodology adopted.

We propose that the Ecohomes method for assessing the carbon dioxide emissions from air conditioning is adopted. This method currently takes account of the following items:

- Cooling degree days – this data should be made available for a range of locations in Ireland
- Fabric heat loss coefficient
- Seasonal COP of the air conditioning system
- Controls efficiency

As this calculation does not take account of internal and solar gains, or the thermal mass of the dwelling, factors for these elements will be necessary. All of these factors can be incorporated by adapting the factors calculated in the overheating assessment of the UK's SAP(2005). This avoids the need for additional data input. As for the overheating assessment, these factors would have to be calibrated to ensure a realistic value representative of all dwelling types is incorporated.

This would provide a more realistic assessment of the dwelling energy consumption than currently proposed for the UK's regulations. It should be noted that the assessment of air conditioning in dwellings is planned to be incorporated in future amendments of UK's building regulations.

#### **5.4 Infiltration**

It should be noted that SAP(2005) calculates air infiltration from a pressure test or an assessment of air leakage from the construction and ventilation systems when a dwelling pressure test is not relied on. The assessment differentiates between steel/timber framed and masonry construction as well as timber and other types of floor construction.

If pressure testing is not to be adopted it is important to ensure that the calculated air infiltration is representative of the performance of the construction used. The current procedure penalises masonry walls when compared with steel and timber, and penalises timber floors when compared with other floor constructions. This may not be representative of current construction standards as studies have shown that masonry construction can easily be made as air tight as timber construction.

## 6 Conclusions and recommendations

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This study has established that thermal mass influences comfort and energy consumption in dwellings. It has concluded that:

- By accounting for thermal mass in dwelling fabric construction could save between 5 and 9% of heating energy consumption if a thermally heavyweight fabric is incorporated. It has been concluded that it is important that the effect thermal mass is incorporated into the assessment of dwelling energy consumption.
- It is important to test for overheating in dwellings to minimise the likelihood of retrofit air conditioning. It is also important to ensure that the effect of thermal mass is correctly accounted for when assessing overheating.
- It is important to take account of the energy consumption of any air conditioning system installed so as to accurately represent the overall energy consumption in dwellings.

We recommend that:

- A fabric admittance factor is included in the heating energy consumption calculation
- A test is made for overheating which contains a fabric admittance factor
- Cooling system energy consumption calculation with a fabric admittance factor is included in the dwelling energy consumption rating

It should be noted that all of the above factors will be important when predicting the energy consumption in buildings other than dwellings and should be incorporated in these methodologies.

## 7 Appendix 1 – model assumptions

### 7.1 Construction Details

#### 7.1.1 Apartments

Element	Lightweight admittance (W/m <sup>2</sup> K)	Heavyweight admittance (W/m <sup>2</sup> K)	Fabric U-value (W/m <sup>2</sup> K)
Ground floor suspended slab	2.8	4.2	0.25
Intermediate floors	1.7	2.8	N.A.
Roof	1.7	2.8	0.22
External walls	1.0	4.4	0.27
Party Walls	2.6	3.5	N.A.
Internal partitions	0.8	3.5	N.A.
Windows	N.A	N.A	2.2
Doors	N.A	N.A.	2.2

## 7.1.2 Semi detached and detached dwellings

Element	Lightweight admittance (W/m <sup>2</sup> K)	Heavyweight admittance (W/m <sup>2</sup> K)	Fabric U-value (W/m <sup>2</sup> K)
Ground floor suspended slab	2.1	4.2	0.25
Intermediate floors	1.7	1.7	N.A.
Roof	1.7	1.7	0.16
External walls	1.0	4.4	0.27
Party Walls	2.6	3.5	N.A.
Internal partitions	0.8	3.5	N.A.
Windows	N.A	N.A	2.2
Doors	N.A	N.A.	2.2

## 7.2 Casual Gains

Area	Time	People (W/m <sup>2</sup> )	Lighting (W/m <sup>2</sup> )	Equipment (W/m <sup>2</sup> )
Lounge	0000-1400	0	0	1
	1400-1800	0 M-F 7.5 S-S	0 M-F 6 S-S	1 M-F 10 S-S
	1800-2400	7.5	6	10
Bedroom	0000-0700	15	0	0
	0700-0800	15	3 M-F 0 S-S	3 M-F 0 S-S
	0800-0900	0 M-F 15 S-S	0 M-F 3 S-S	0 M-F 3S-S
	0900-2300	0	0	0
	2300-2400	15 M-F 0 S-S	3 M-F 0 S-S	3 M-F 0 S-S
Ancillary	0000-0700	0	0	1
	0700-0800	22.5	6 M-F 0 S-S	10 M-F 1 S-S
	0800-0900	0	0	1
	0900-1000	0 M-F 22.5 S-S	0 M-F 6 S-S	1 M-F 10 S-S
	1000-1400	0	0	1
	1400-1500	0 M-F 22.5 S-S	0 M-F 6 S-S	1 M-F 10 S-S
	1500-2000	0	0	1
	2000-2100	22.5	6	10
	2100-2400	0	0	1

Figure 14 Dwelling casual gains

## 7.3 Natural ventilation openings

Windows were assumed to contain trickle vents to maintain a background infiltration of on average 0.25 air changes per hour. Window openings for summer ventilation were set at 10% of the glazing area representing a typical design solution.

#### 7.4 Weather data

Typical weather data for Dublin was used in the model, a summary of which is shown in the following figure.

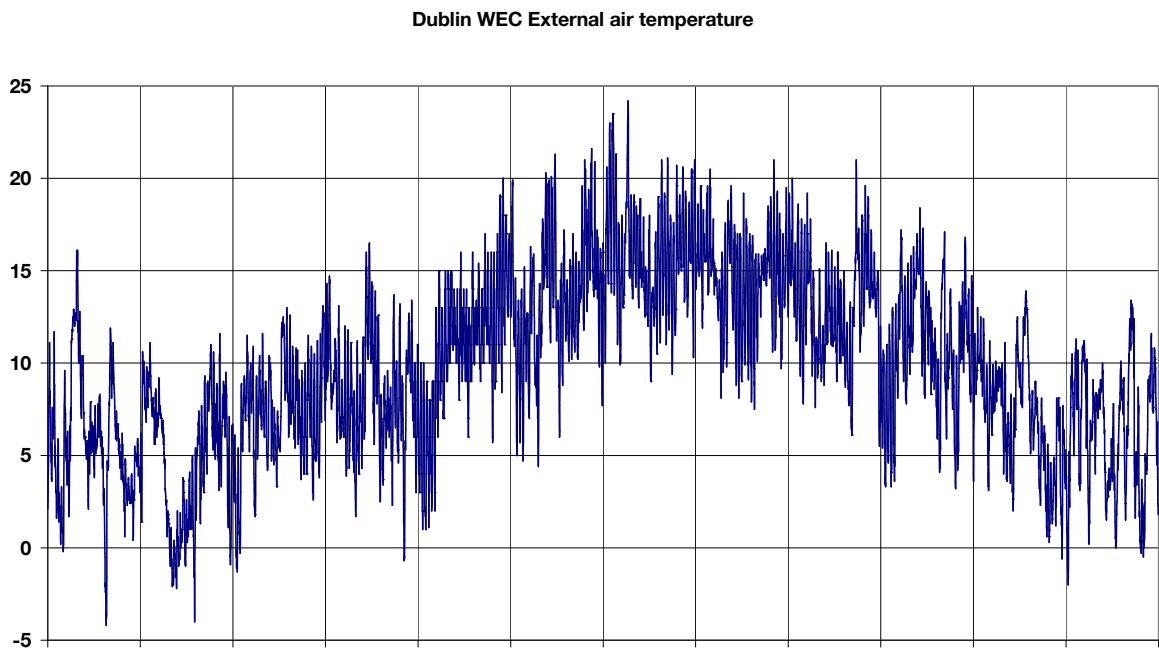


Figure 15 **Dublin WEC external air temperature profile used in the model**

## 8 References

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