DECC – Thin Internal Wall Insulation

Report

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DECC Thin IWI Analysis

Quality information

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Revision history

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1	10/06/2016	Updates following client feedback	**Daniel Cooke,** Consultant **Ewan Jones** Principal Consultant	10/06/2016	**David Ross** Regional Director
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Executive Summary

Executive Summary

This study has assessed the effects of installing thin internal wall insulation (IWI) in existing housing. The analysis suggests that using thin insulation products can achieve up to 57% of the energy saving of conventional (thicker) wall insulation and potentially overcome many of the challenges that make conventional IWI difficult to deploy widely.

Internal Wall Insulation (IWI) is the term used to describe insulation applied to the internal face of external walls. This energy efficiency measure is often applied to older existing buildings where the existing building fabric is either not insulated or is insulated to a low standard. Conventional IWI is generally between 50mm and 150mm thick.

Conventional IWI has had relatively low take-up in the UK. It is expensive, disruptive to install, takes up internal space, is not accessible for the DIY market and can change the physics of building fabric, sometimes resulting in unintended consequences such as excessive thermal bridging, overheating, damp and other moisture problems.

Using ‘thin’ insulation systems (10mm to 20mm) mitigates many of these challenges. It is cheaper, simpler to apply, takes up less space and has less impact on the physics of the building fabric than conventional IWI. Although the thermal performance of thinner insulation will normally be poorer than thicker alternatives, the net potential to save energy at a national level may be greater because it can more easily be deployed widely and it reduces the barriers to take-up by consumers.

DECC appointed AECOM to undertake an initial study to understand better the performance of thin IWI in terms of energy saving and overheating risk. AECOM used dynamic thermal simulation to simulate a typical semi-detached house. The study evaluated performance across 65 alternative scenarios comprising combinations of each of the following:

- three levels of internal wall insulation (0mm, 10mm, 20mm),
- five existing building constructions (solid brick, unfilled cavity, partially filled cavity, concrete, solid wall with conventional internal wall insulation) [1], and
- five combinations of occupancy patterns and UK location.

Results

The calculated percentage reduction in annual heating demand achieved by adding 10mm IWI varies between 5% and 9% depending on construction type (averaged across occupancy pattern and UK location). When adding 20mm IWI, this reduction improved to 7% to 14% compared to no IWI. The general trend is that thin IWI makes bigger savings when applied to walls with a higher initial U-value (in this case the solid brick wall has the highest starting U-value). The percentage reduction does depend on the occupancy profile and location, but these variations are relatively small.

It is useful to contrast this with conventional internal wall insulation. For solid brick walls, the analysis showed a percentage reduction from installing 10mm and 20mm IWI of 9% and 14% respectively compared to a 25% reduction from using conventional internal wall insulation. Hence, the analysis shows that 20mm of insulation delivers 57% of the energy savings of much thicker conventional alternatives.

Analysis was undertaken to determine the impact of thin IWI on the time it takes radiators to warm up the living room and master bedroom when the heating is first turned on. The fitting of IWI was shown to typically reduce heat loss from the house and allow rooms to warm-up more quickly. However, at any given moment, the increase in temperature achieved by the thin IWI is less than 1°C. It is thought that this small temperature difference will not be noticeable to most occupants, however further review/research is required to verify this.

A final set of analysis was undertaken to consider the effects of thin IWI on the overheating risk of building occupants during the summer in the living room and bedroom. Whilst the installation of thin IWI did impact on the number of hours that temperature thresholds were exceeded (evaluated thresholds from 25°C to 28°C), the impact was small relative to the number of hours the untreated dwellings are calculated to exceed the thresholds already.

[1] Where conventional IWI is already installed the addition of thin IWI was not assessed.

Introduction

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Introduction

Conventional Internal Wall Insulation (IWI) is seen as a valuable part of domestic energy efficiency policy but it is expensive, disruptive to install, takes up space, is not accessible for the DIY market and can change the physics of building fabrics sometimes resulting in unintended consequences such as excessive thermal bridging, condensation and overheating.

Using thinner insulation systems (10mm to 20mm) mitigates many of these challenges by being cheaper, simpler to apply and taking up less space. Thin IWI has less impact on the physics of the building fabric than conventional IWI; however there may still be risks associated with its application in some cases. Although the thermal performance of thinner insulation will normally be poorer than thicker alternatives the net potential to save energy at a national level may be greater because it can more easily be deployed widely and reduce barriers to take-up by consumers.

To assess the potential effects of thin IWI, DECC appointed AECOM to undertake a study using dynamic thermal simulation (DTS) to understand the range and variation in performance that thin IWI might be expected to have according to a building's thermal mass and the residents' occupancy profile in terms of energy saving and overheating risk. Condensation risk was not included in this analysis.

Methodology

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Methodology

This section provides an overview of the modelling methodology; full details of the modelling inputs can be found in Appendix 1.

Fabric Specification

Housing construction has developed considerably over the last 120 years. These changes include different building fabric specifications and different building forms. This study has considered four construction types to represent a wide range of different building fabric specifications spanning the last 120 years.

- Solid brick circa 1900;
- Unfilled cavity;
- Partial fill cavity;
- Concrete construction (no cavity).

Each of these construction types has been modelled three times; the first as described above and then two variant options with 10mm and 20mm thicknesses of thin IWI applied respectively. Solid brick circa 1990 with current typical IWI has also been assessed to compare the performance of thin IWI with more conventional IWI.

The specification for the thin internal wall insulation is based on a typical thin IWI product available in the UK market.

Parameter	Insulation
Thickness (mm)	10 and 20
Thermal conductivity (W/mK)	0.0515
Density (kg/m³)	186.4
Specific heat capacity (J/kgK)	2,000

Table 1: Performance parameters for thin internal wall insulation used in this analysis.

The effects of the IWI on the U-value of each of these construction types have been calculated using the BRE U-value Calculator software. U-value calculations do not account for the effects of non-repeating thermal bridges as these are specific to individual dwellings; this assumption also implies that the thin IWI would be fitted across the whole surface of the external wall (i.e. behind skirting boards, coving and the area of external wall that lies between the floors and ceilings of adjacent storeys). Assuming skirting boards and coving are present in every room then these areas would amount to approximately 7% of the total external wall area. In a house with no coving this would reduce to approximately 5% of the total external façade area. In practice, the areas covered by coving and skirting board would not be at the untreated wall U-value, as these elements would have some level of positive impact on the U-value, as skirting boards are normally wooden and more modern coving is often made from polystyrene, which would have an insulating effect.

Table 2 shows the U-values calculated with the BRE U-value calculator used in this analysis:

External Wall Construction	U-Value (W/m²K)		
	Without thin IWI	With 10mm IWI	With 20mm IWI
Solid brick circa 1900	1.70	1.28	1.03
Unfilled cavity	1.40	1.10	0.91
Partially filled cavity	0.60	0.54	0.49
Concrete construction (no fines concrete)	1.30	1.04	0.86
Solid brick circa 1900 with standard IWI	0.50 [Note 1]	N/A	N/A

[Note 1] The U-value indicated is for standard 'thick' IWI. This was used as a comparator and no additional 'thin' IWI was added for this construction type.

Table 2: U-values calculated for each of the five fabric specifications with each of the three levels of thin IWI included.

Building Form

A single typical building form was developed based on a typical semi-detached property. The building form was derived using data from the Cambridge Housing Model which in turn is based on the English Housing Survey 2011 data[2]. The resulting dwelling model has 3 bedrooms, living, dining and kitchen areas, a WC and a bathroom. The floor area of the dwelling is 90m², see Figure 1. Full details of the building form can be found in Appendix 1.

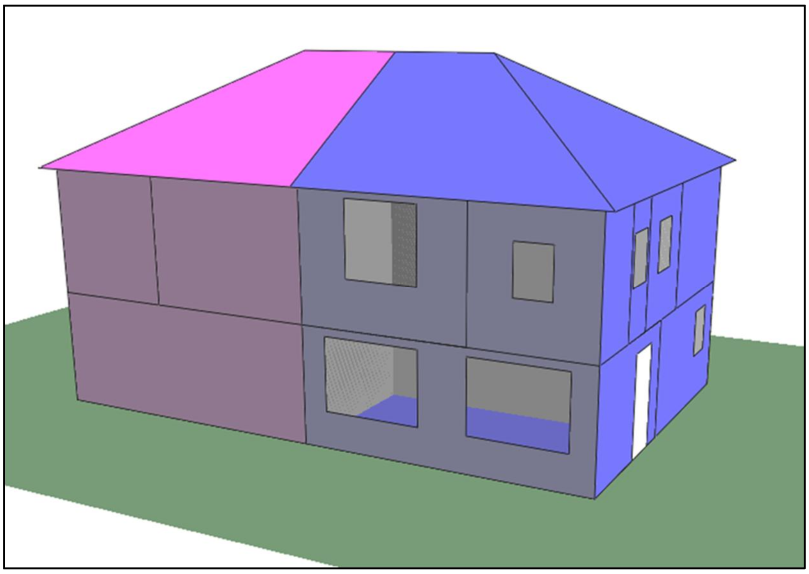

Figure 1: Screenshot of the typical dwelling form developed for this study.

This building form was modelled with each of the five construction types described above. The results presented in this report provide an initial understanding of the magnitude difference between the current situation (both without IWI and with standard IWI) and thin IWI options discussed, based on this typical dwelling form. In practice, the impact of adding thin IWI on the building's thermal performance will depend on the house type due to the different form factors and external envelope areas; e.g. a detached house will have more external wall area than the semi-detached form, and the semi-detached form will have more than a terrace house. This will alter the impact on thermal performance from the inclusion of thin IWI as in these scenarios the ratio of external envelope to external wall is different.

2 https://www.gov.uk/government/statistics/cambridge-housing-model-and-user-guide

Occupancy & Location Scenarios

As well as considering the effects of five different construction types, this study considered the effect of five different combinations of occupancy patterns and geographical location.

Occupancy

The study considered four different occupancy patterns. This accounts for the effects of different hours of use for heating systems, appliances, lights and how windows may be opened and closed in warm weather. Details of the occupancy patterns are summarised here and included in more detail in Appendix 1.

i. **Standard Assessment Procedure (SAP)**

SAP occupancy assumptions were recreated in the dynamic thermal modelling (DTM) to provide the base case occupancy profile for this study.

ii. **Modified SAP**

A modified SAP scenario was based on the findings of the Energy Follow-up Survey[3]. The Survey identified a number of differences between the current SAP assumptions and the findings from the surveyed households. One key finding was that whilst the SAP occupancy profile for weekdays is representative of the surveyed dwellings; unlike SAP, the surveyed dwellings were found to typically not modify the heating times at weekends.

iii. **Retired Couple**

Model inputs used for the occupancy pattern for a retired couple were developed from first principles using the heating set-points defined in SAP.

iv. **Single working-age person**

Model inputs used for the occupancy pattern for a single working age person were developed from first principles using the heating set-points identified by the Energy Follow-up Survey.

Location

The first four of the five scenarios modelled comprised each of the above occupancy patterns modelled using industry standard weather data for Manchester; CIBSE TRY05 (Chartered Institute of Building Services Engineers Test Reference Year 2005[4]). Manchester is deemed to be a representative location within the UK being broadly at the centre of the country geographically. The fifth scenario was modelled using the SAP occupancy scenario and the standard weather data for Edinburgh; CIBSE TRY05. This provides analysis of the impact of weather on the performance of thin IWI.

[3] https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011

[4] The Test Reference Year (TRY) is composed of 12 separate months of data each chosen to be the most average month from 23 years of data, (typically 1983 to 2005 but this varies depending upon data availability). These average months are then spliced together to form a single year; a smoothing process is carried out to avoid having step changes at the start/end of each month (http://www.exeter.ac.uk/media/universityofexeter/research/newsandevents/newsandeventsarchive/Weather_Files.pdf)

Details of all of these occupancy scenarios are provided in Appendix 1. Table 3 provides a summary of the key assumptions.

Variable	SAP	Energy Follow-up Survey
Applicable Occupancy Scenarios	– SAP – SAP in Scotland – Retired Couple	– Modified SAP – Single Working Person
Zone 1 heating temperature	21.0°C	20.2°C
Zone 2 heating temperature	18.0°C	19.1°C
Months in which heating operates	September – April	Mid October – April
Lighting	Follows occupancy profile Based on Appendix L1 of SAP	Follows occupancy profile
Appliances	Follows occupancy profile Based on Appendix L2. of SAP	Fridge, freezer, electric oven, gas hob, 4 loads of washing per week, 3 loads of drying per week in winter only, 2 TVs

Table 3: Key occupancy pattern inputs.

All scenarios were modelled with the assumption that windows will be opened during hot conditions to help keep the dwelling cool. Windows were modelled as being open when internal temperatures are high and the dwelling is occupied and the occupants are awake; when occupants are asleep, the downstairs windows are closed and the upstairs windows are restricted to 10% opening. Windows start to open when the internal temperature exceeds 23°C and are fully open if the temperature reaches 26°C; between these two temperatures the degree of window opening varies linearly.

Dynamic Thermal Modelling

To carry out dynamic thermal simulations, AECOM uses the industry standard <Virtual Environment> v.2015 software suite, from Integrated Environmental Solutions Ltd. The IES <VE> is an integrated suite of applications based around one 3D geometrical model. The modules used for this project include “SunCast” for solar shading analysis and “Apache-Sim” for thermal simulation calculations and MacroFlo for bulk air movement calculations.

SunCast generates shadows and internal solar insolation from any sun position defined by date, time, orientation, site latitude and longitude. This shading information is stored in a database and is used to take account of shading from surroundings in subsequent thermal simulation calculations.

Apache-Sim is a dynamic thermal simulation program based on first-principles mathematical modelling of the heat transfer processes occurring within and around a building. It qualifies as a Dynamic Model in the CIBSE system of model classification, and exceeds the requirements of such a model in many areas. The program provides an environment for the detailed evaluation of building and system designs, allowing them to be optimised with regard to comfort criteria and energy use.

MacroFlo is a program for analysing bulk airflow: infiltration, natural ventilation, facade design, and mechanical ventilation. The system can be used to demonstrate how to reduce the necessity for air conditioning using natural or mixed-mode strategies. Typical strategies can include single-sided ventilation, cross-ventilation, etc.

The building models were populated with information relating to the following parameters described earlier in this section:

- Building fabric;
- Location and weather;
- Internal heat gains (occupants, lights, appliances etc.);
- Control of window openings.

Fabric elements were built up using the building materials and thicknesses deemed to best reflect typical practice for each construction type.

Thus the analysis considered five construction types, five occupancy and location scenarios and three levels of thin IWI. Considering every combination of these variables results in 65 simulations as is illustrated in Table 4.

			Scenario				
			SAP	Modified SAP	Scotland SAP	Retired Couple	Single Working Person
Thin IWI	None	Construction Type: Solid Brick					
		Unfilled Cavity					
		Partially Filled Cavity					
		Concrete					
		Solid Brick with conventional IWI					
	10mm	Construction Type: Solid Brick					
		Unfilled Cavity					
		Partially Filled Cavity					
		Concrete					
		Solid Brick with conventional IWI					
	20mm	Construction Type: Solid Brick					
		Unfilled Cavity					
		Partially Filled Cavity					
		Concrete					
		Solid Brick with conventional IWI					

Table 4: Illustration of 65 simulations required to consider all combinations of variables.

Results & Analysis

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Results & Analysis

The analysis has considered three principal dwelling performance parameters that are affected by the installation of thin IWI:

1. Heating energy requirements
2. Warm-up time
3. Overheating risk

Heating Energy Requirements

The annual heating energy requirement of a building is a function of many variables including:

- Outside temperature;
- Inside temperature;
- Fabric specification;
- Air leakage rate;
- Ventilation rate;
- Internal heat gains;
- Amount of time for which the heating is on.

The analysis considered the effects of change of most of these variables (air leakage and ventilation rates were kept constant across all simulations).

The results of the dynamic thermal simulations were analysed to quantify the calculated annual heating energy requirements for each simulation and identify the impact of the installation of thin IWI. Table 5 and Figure 2 show the modelled annual heating demands for all simulations.

Occupancy Profile	Modelled Annual Heating Demand (MWh)												
	Solid Brick circa 1900 (initial wall U-value = 1.7W/m²K)			Unfilled Cavity (initial wall U-value = 1.4W/m²K)			Partially Filled Cavity (initial wall U-value = 0.6 W/m²K)			Concrete (initial wall U-value = 1.3W/m²K)			Solid Brick circa 1900 with current IWI (initial wall U-value = 0.5W/m²K)
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	
SAP	9.90	8.89	8.33	9.84	9.09	8.63	6.60	6.28	6.10	9.00	8.37	7.97	7.14
Modified SAP	10.13	9.25	8.77	10.07	9.40	9.01	7.19	6.85	6.67	9.35	8.80	8.46	7.74
Scotland SAP	11.51	10.37	9.74	11.44	10.59	10.08	7.76	7.39	7.18	10.49	9.78	9.33	8.40
Retired Couple	12.57	11.33	10.64	12.49	11.58	11.02	8.51	8.13	7.91	11.45	10.69	10.19	9.19
Single Working Person	8.71	8.09	7.76	8.71	8.22	7.94	6.46	6.18	6.03	8.12	7.75	7.51	7.05
	% Change from no IWI												
SAP	N/A	10.2%	15.9%	N/A	7.7%	12.3%	N/A	4.8%	7.6%	N/A	6.9%	11.4%	N/A
Modified SAP	N/A	8.7%	13.4%	N/A	6.7%	10.6%	N/A	4.6%	7.2%	N/A	5.8%	9.5%	N/A
Scotland SAP	N/A	9.9%	15.4%	N/A	7.4%	11.9%	N/A	4.8%	7.5%	N/A	6.7%	11.0%	N/A
Retired Couple	N/A	9.8%	15.4%	N/A	7.3%	11.8%	N/A	4.5%	7.1%	N/A	6.7%	11.0%	N/A
Single Working Person	N/A	7.1%	10.9%	N/A	5.6%	8.9%	N/A	4.4%	6.7%	N/A	4.6%	7.5%	N/A

Table 5: Modelled annual heating demand variation across all 65 simulations.

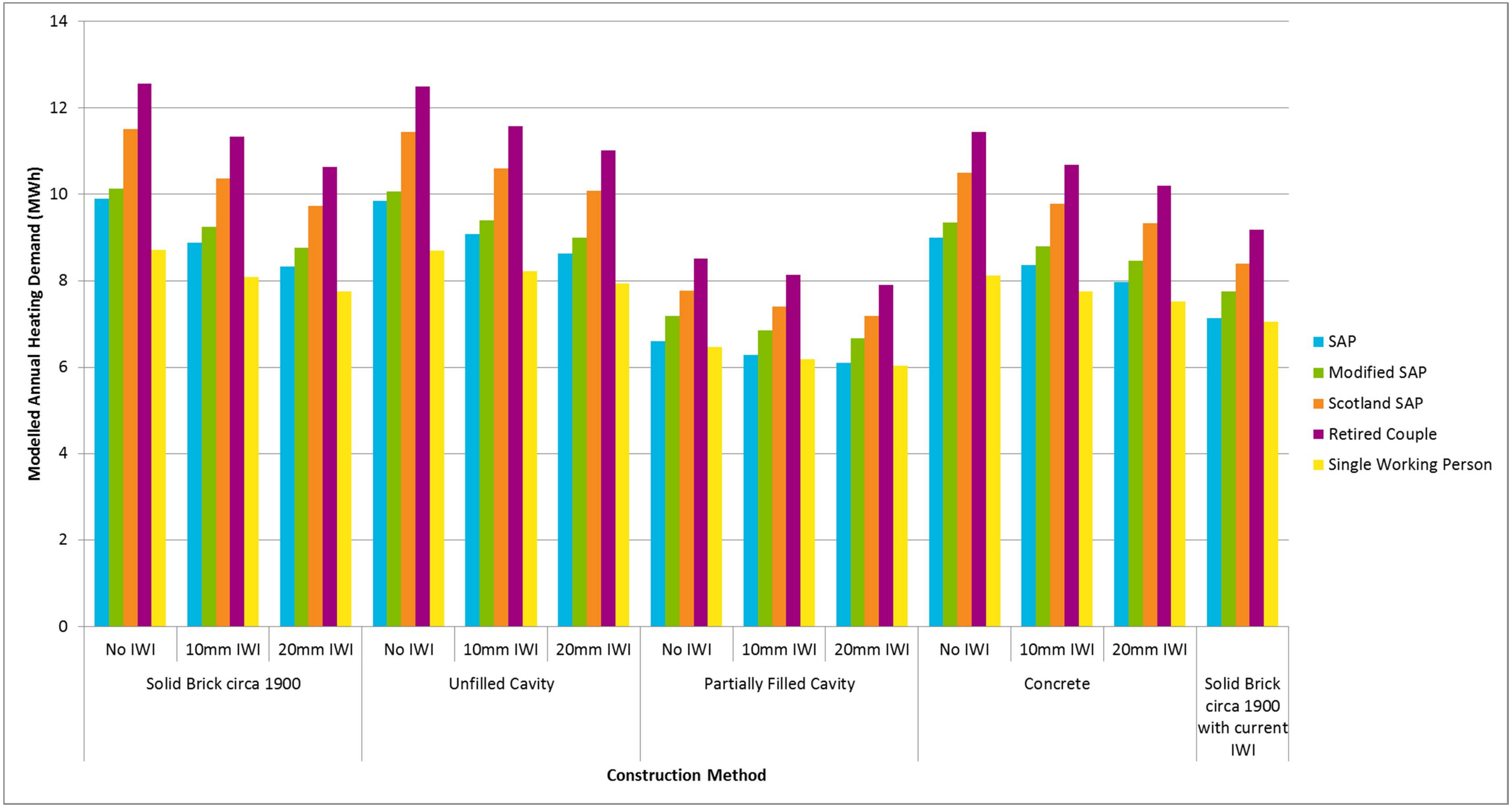


Figure 2: Modelled annual heating demand variation across all 65 modelled scenarios.

Discussion of the Effect of Fabric Specification on Heating Requirements

The calculated percentage reduction in annual heating demand achieved by adding 10mm of IWI varies between an average[5] of 4.6% for a house which has a partially filled cavity wall up to an average of 9.1% for a solid brick dwelling. The calculated savings for a 20mm thick layer of IWI vary between an average of 7.2% and 14.2% for the same two fabric specifications. Table 6 shows a summary of the calculated reductions in annual heating energy requirements achieved when thin IWI is applied to different wall types - these results are averaged across all modelled occupancy and location scenarios.

Fabric Specification	Average Reduction In Annual Heating Energy Requirement	
	10mm IWI	20mm IWI
Solid Brick circa 1900 (initial wall U-value = 1.7W/m²K)	9.1%	14.2%
Unfilled Cavity (initial wall U-value = 1.4W/m²K)	7.0%	11.1%
Partially Filled Cavity (initial wall U-value = 0.6 W/m²K)	4.6%	7.2%
Concrete (initial wall U-value = 1.3W/m²K)	6.1%	10.1%

Table 6: Summary of modelled annual heating demand reduction by fabric specification.

The observed trend is that thin IWI makes bigger savings when applied to walls with a higher initial U-value; in this case the solid brick wall has the highest starting U-value with the partially filled cavity wall having the lowest starting U-value.

Comparison of Solid Brick Wall with Conventional (Thick) IWI and Thin IWI on Heating Requirements

From the data presented in Table 5 it is possible to compare the impact of thin IWI and current IWI on the annual heating requirements for solid brick walls built circa 1900. The average annual heating requirement of the solid brick wall without IWI is 10.6MWh. Applying conventional (thick) IWI reduces the heating requirement by 25%. In contrast, the addition of 10mm and 20mm of thin IWI to the solid brick wall on average reduces the annual heating requirement by 9% and 14% respectively. This lesser impact of thin IWI is expected as the U-value of the solid brick wall (and the reduction in the annual heating requirement) improves as the thickness of IWI is increased.

Discussion of the Effect of Occupancy & Location Scenario on Heating Requirements

The greatest calculated savings are for the SAP occupancy profile (7.4% on average for 10mm IWI and 11.8% on average for 20mm IWI) whilst the lowest calculated savings are for the single working person (5.4% on average for 10mm IWI and 8.5% on average for 20mm IWI).

[5] Averaged across all five occupancy profiles considered.

The assumed occupancy profile for the single working person was expected to show the smallest percentage savings and the lowest heating requirement because the heating is on for less time than for other occupancy profiles (although the heating is set to the higher of the two temperatures considered; see Table 3 on page 13).

The occupancy profile that was expected to show the greatest savings from the addition of thin IWI was the retired couple on the basis that this scenario has the longest heating hours and uses the higher of the two heating set-point temperatures. Figure 2 shows that the annual heating demand for the retired couple is consistently higher than the other scenarios and the absolute calculated energy savings achieved by thin IWI are greatest for this scenario. However the retired couple scenario shows marginally lower percentage savings than the SAP standard occupancy base case. The higher savings for the SAP scenario may be due to the complex interaction of internal gains and heating times and set-points. Further detailed analysis would be required to isolate the motivating vectors for this finding.

The overall findings show a consistent improvement regardless of scenario or location:

- **Occupancy profile:** The variation in heat requirement by occupancy profile is less significant than the average reduction in heat requirement by construction type. For example, the largest variation in space heating requirement by occupancy profile was observed by adding 20mm of thin IWI to a solid brick walled dwelling. In this case the reduction ranged from 10.9% to 15.9% depending on the occupancy profile. However, this range of 5% by occupancy profile is significantly less than the average reduction of 13.9% across all occupancy profiles. Some variations are significantly smaller, for example the calculated range for applying 10mm of thin IWI to a partial fill cavity walled dwelling is just 0.4% by occupancy profile compared to a 4.6% saving on average across all occupancy profiles.
- **Location:** The variation in heat requirement by location is relatively small compared to the average reduction for the construction type. Whilst the calculated reduction in space heating requirements is influenced by the location of the dwelling, the greatest range observed in this analysis was between 15.4% reduction for adding 20mm of thin IWI to a solid brick walled dwelling in Edinburgh to 15.9% for the same dwelling in Manchester (i.e. a range of just 0.5%).

Warm-up Time

The rated output of heat emitters (radiators, underfloor heating etc.) in each space have been sized in accordance with standard practice based on the calculated heat loss from each room (see Appendix 1 for details). The capacity of the heat emitters governs the rate at which rooms heat up when the heating first turned on. For the purposes of this analysis it was assumed that radiators would not be changed when thin IWI is fitted, therefore it would be expected that the fitting of IWI would result in the rooms warming up more quickly.

To quantify this effect, the rate of temperature rise was analysed in the living room and master bedroom of each dwelling that was modelled. The graphs below compare the rate of temperature rise for with no thin IWI, 10mm of IWI and 20mm of IWI for selected combinations of dwelling fabric and occupancy scenario (a full set of 50 graphs can be found in Appendix 2). These graphs show the rate of temperature rise for the 11th of January which was the day on which the internal temperature of the house dropped to the lowest level overnight. The temperatures recorded on this day are below the level that most occupants would find acceptable; in reality it is likely that occupants would modify the heating controls to accommodate extreme cold weather.

Figure 3 shows the modelled rate of temperature rise on the 11th of January for the master bedroom in the solid brick dwelling with the modified SAP occupancy scenario. In this option during the morning heating period the room does not reach its target temperature with any of the three IWI levels. During the longer afternoon/evening heating period the target temperature is met in all cases. In the example case shown in Figure 3, the addition of the 20mm of thin IWI allows this target temperature to be achieved in four hours rather than the seven hours taken by the uninsulated base case in the afternoon/evening. This means that the room warms up quicker when the room is occupied for the main period of the afternoon/evening. However, it is important to note that for all three IWI levels there is an initial rapid rise in temperature in the room and the absolute difference in temperatures with and without IWI is at most 1°C – hence this difference in warm-up time may not be perceived as significantly different by the occupant.

However, in most cases considered (shown in Appendix 2), the difference in warm-up time is smaller than this. For example, Figure 4 shows the modelled rate of temperature rise on the 11th of January for the living room in the partially filled cavity dwelling with the retired couple occupancy scenario where little difference in warm-up time is observed. In such cases, the occupants would probably not notice any difference in the time taken for rooms to heat up or if rooms started the day colder or warmer with the inclusion of IWI.

Figure 3 also highlights colder starting temperatures with no IWI in the master bedrooms compared to 20mm of IWI. The inclusion of IWI reduces the heat lost through the external walls compared to no IWI. Additionally the master bedroom is above the living room, so internal conduction would transfer heat from the living room to the master bedroom.

Figure 4 shows that the living room is colder first thing in the morning when additional IWI is applied. However, it is important to note that this trend is only observed in the partially filled cavity wall construction scenarios, which is the opposite to the other construction methods which follows the expected pattern of reduced heat loss overnight, and warmer starting temperatures, with IWI installed. This difference could be due to the impact of the IWI on the thermal mass of the partially filled cavity wall construction being more pronounced. By reducing the thermal mass of the house it will result in faster warm up times, as shown, but at the same time will result in faster cool down times, so the rooms will be at a lower temperature first thing in the morning.The SAP method of assessing the energy performance of dwellings assumes that the target heating temperature is reached quickly when the heating is turned on; the results of this analysis show that this might not always be a reasonable assumption. Furthermore, the analysis highlights that in many cases the modelled dwellings fail to reach the target temperature for several hours; this implies that the standard method for sizing domestic radiators (based on steady-state heat loss calculations) may not be adequate to quickly achieve comfortable temperatures in extreme cold weather.

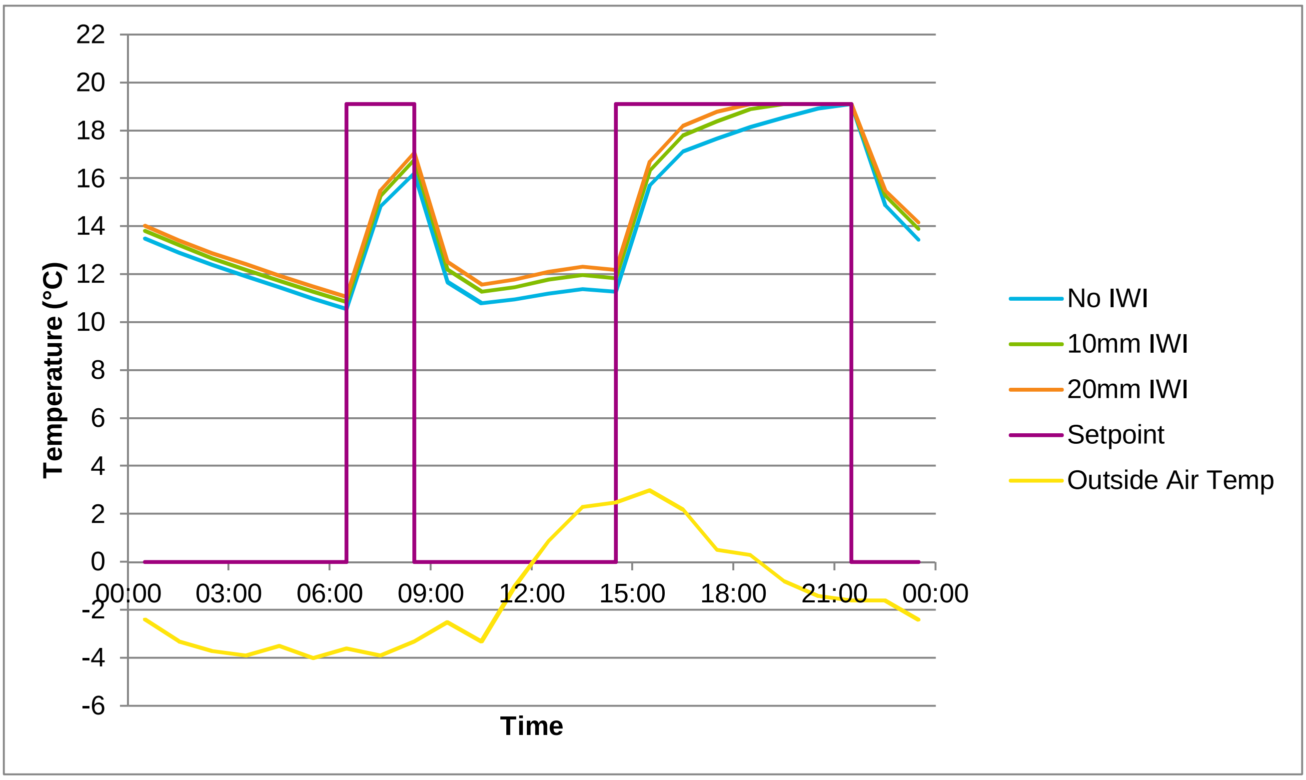


Figure 3: Modelled rate of temperature rise on 11th January for the master bedroom in the solid brick dwelling with the modified SAP occupancy scenario.

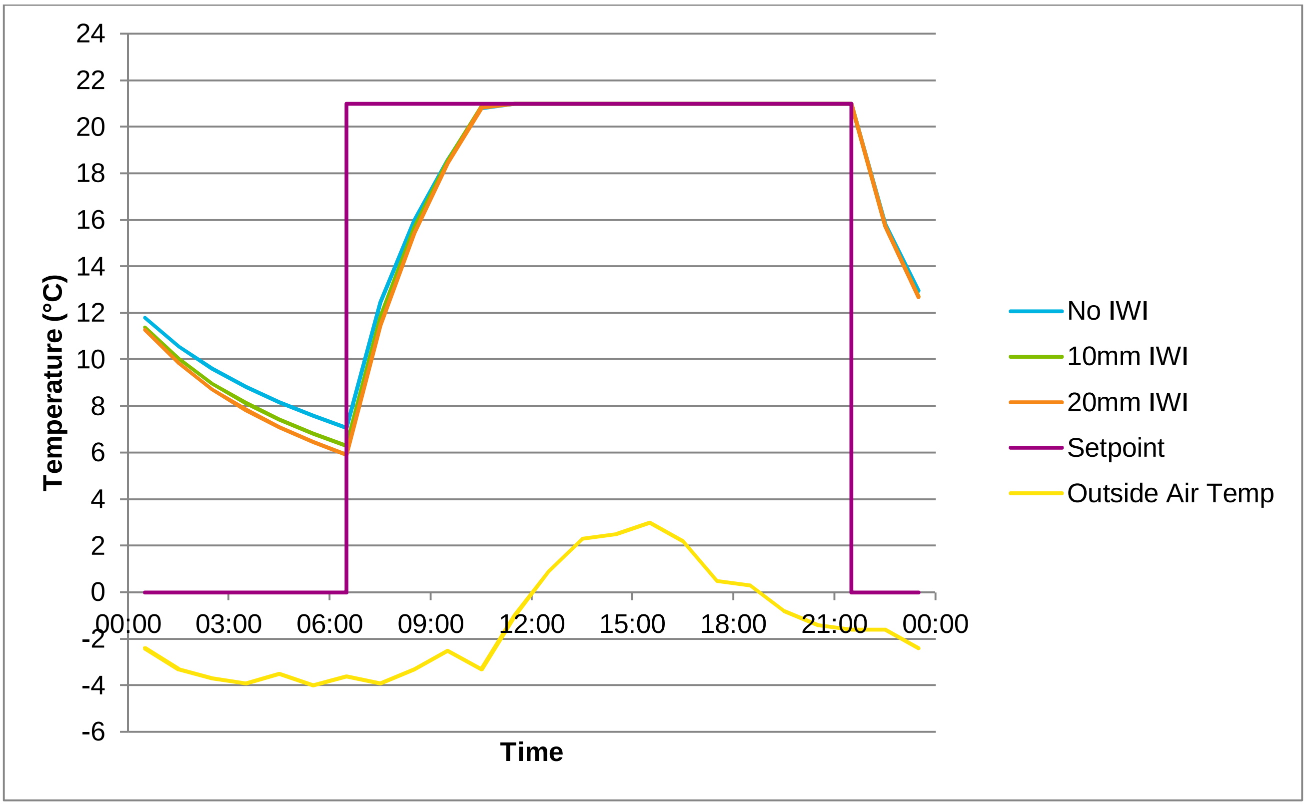


Figure 4: Modelled rate of temperature rise on 11th January for the living room in the partially filled cavity dwelling with the retired couple occupancy scenario.

Table 7 and Table 8 show the number of hours each modelled dwelling takes for the target temperature to be achieved in the living room and master bedroom on 11th January. As highlighted above, in most cases, the number of hours that it takes a dwelling to warm-up is not significantly reduced by the addition of IWI. Close analysis of the results shown in Appendix 2 reveals that the small differences in calculated temperature during the warm-up period are always less than 1°C. It is thought that this small temperature difference will not be noticeable to most occupants, however further review/research is required to verify this.

The software was set-up for 60 minute reporting. The results show limited variation in warm-up time between IWI thicknesses at this time resolution. The software could be set-up at shorter time steps in further work to better resolve any differences but the benefit of this is currently unclear from the above discussion i.e. such differences in warm-up times do not appear to be significant.

	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with Standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI
SAP	3	3	3	3	2	2	2	2	2	3	3	2	2
Modified SAP	5	4	4	4	4	3	3	3	3	4	4	4	3
Scotland SAP	3	3	3	3	2	2	2	2	2	3	3	2	2
Retired Couple	5	5	5	5	5	5	5	5	5	5	5	5	5
Single Working Person	5	5	5	5	5	5	5	5	5	5	5	5	5

Table 7: Number of hours simulated dwellings take to reach their target heating temperature in the living room.

	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with Standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI
SAP	5	3	3	3	2	2	3	2	2	5	4	3	2
Modified SAP	7	5	4	4	3	3	4	3	3	8	6	6	3
Scotland SAP	5	3	3	3	2	2	3	2	2	5	4	3	2
Retired Couple	5	4	4	3	3	3	4	4	4	5	4	4	3
Single Working Person	5	5	5	5	5	5	5	5	5	5	5	5	5

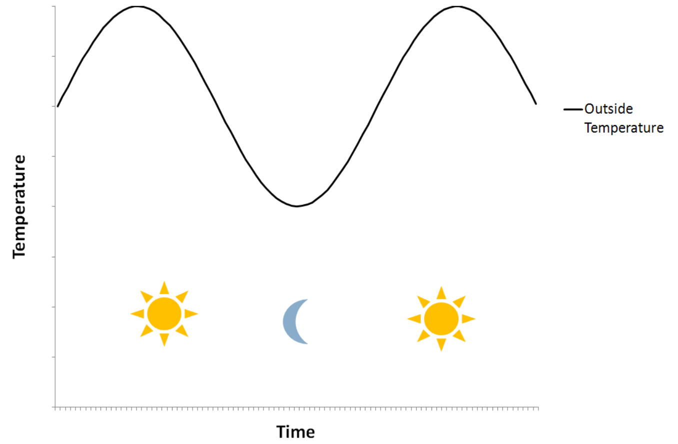
Table 8: Number of hours simulated dwellings take to reach their target heating temperature in the master bedroom.

Overheating Risk Assessment

Thermal mass is a term used to describe the ability of a building's fabric to absorb and store heat. Careful utilisation of this effect can help to achieve a more stable internal temperature than might be achieved using light-weight structures.

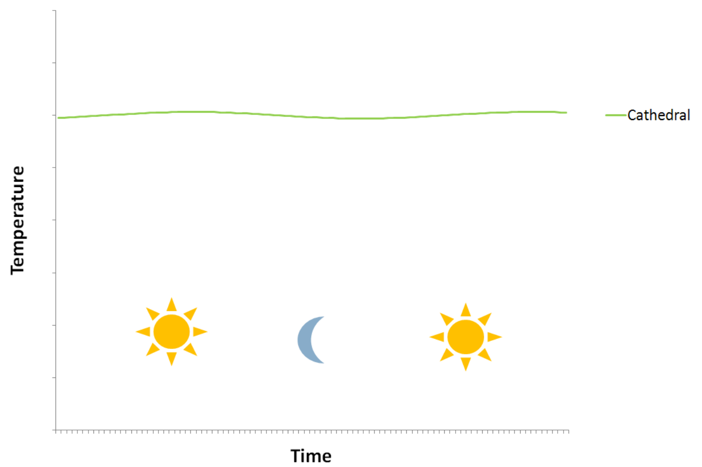
An extreme case of a building with low thermal mass is a tent. The temperature in a tent is generally very close to that of the outside air. Cathedrals have a much higher thermal mass and so the temperature variation is much less. This is shown in Figure 5 (a) and (b).

(a)



Buildings with low thermal mass can heat up rapidly as the external temperature rises. The extreme example of this is a tent.

(b)



Buildings with high thermal mass take longer to change temperature and so can provide a stable internal environment. The extreme example of this is a cathedral.

Figure 5: Illustration of how thermal mass can moderate internal temperature variations.

When effectively combined with a night cooling strategy thermal mass can be a very effective method of keeping occupied spaces cool during the day. However, in most cases, buildings with a high thermal mass will have higher internal temperatures at night than an equivalent light-weight building. Spaces with a low thermal mass can be cooled more rapidly at night by allowing cool night air to flow into the occupied space. In the context of a dwelling this effect can most effectively be harnessed by designing bedroom spaces to have a low thermal mass whilst living spaces have a higher thermal mass.

Adding IWI to a dwelling places a layer of insulation between the occupied space and the thermal mass of the external walls. This might increase the risk of the living spaces overheating in warm weather as the effectiveness of the thermal mass to keep the occupied space cool is reduced. Conversely it might be expected that the risk of overheating at night in bedrooms would be reduced by the addition of thin IWI.

To consider the effects of IWI on the overheating risk of building occupants, the study has quantified the extent of summer-time overheating by analysing the amount of time for which the dwelling room temperatures are outside the targeted temperature ranges as defined in CIBSE guidance. CIBSE Guide A 2006 recommends that living spaces do not exceed 28°C and that bedrooms do not exceed 26°C for more than 1% of their respective occupied periods. CIBSE Guide A 2015 provides similar guidance for bedrooms but is less explicit for living spaces. Appendix 3 shows graphs of the number of hours that the modelled master bedrooms and living spaces exceed 25°C, 26°C, 27°C and 28°C.

Figure 6 and Figure 7 show the number of hours that the modelled living rooms exceed 26°C and 28°C respectively. From these two graphs it can be seen that the addition of thin IWI causes an increase in the number of occupied hours over these temperatures in almost every case.

On average the increase in the number of occupied hours over 26°C in living rooms is 7 hours per year across all scenarios. The greatest increase is observed from adding 20mm of IWI to the partially filled cavity for the Retired Couple scenario which results in an increase in the number of occupied hours over 26°C from 129 hours, without any IWI, to 151 hours with 20mm IWI. This increase is small relative to the number of hours that the untreated dwelling is calculated as exceeding 26°C.

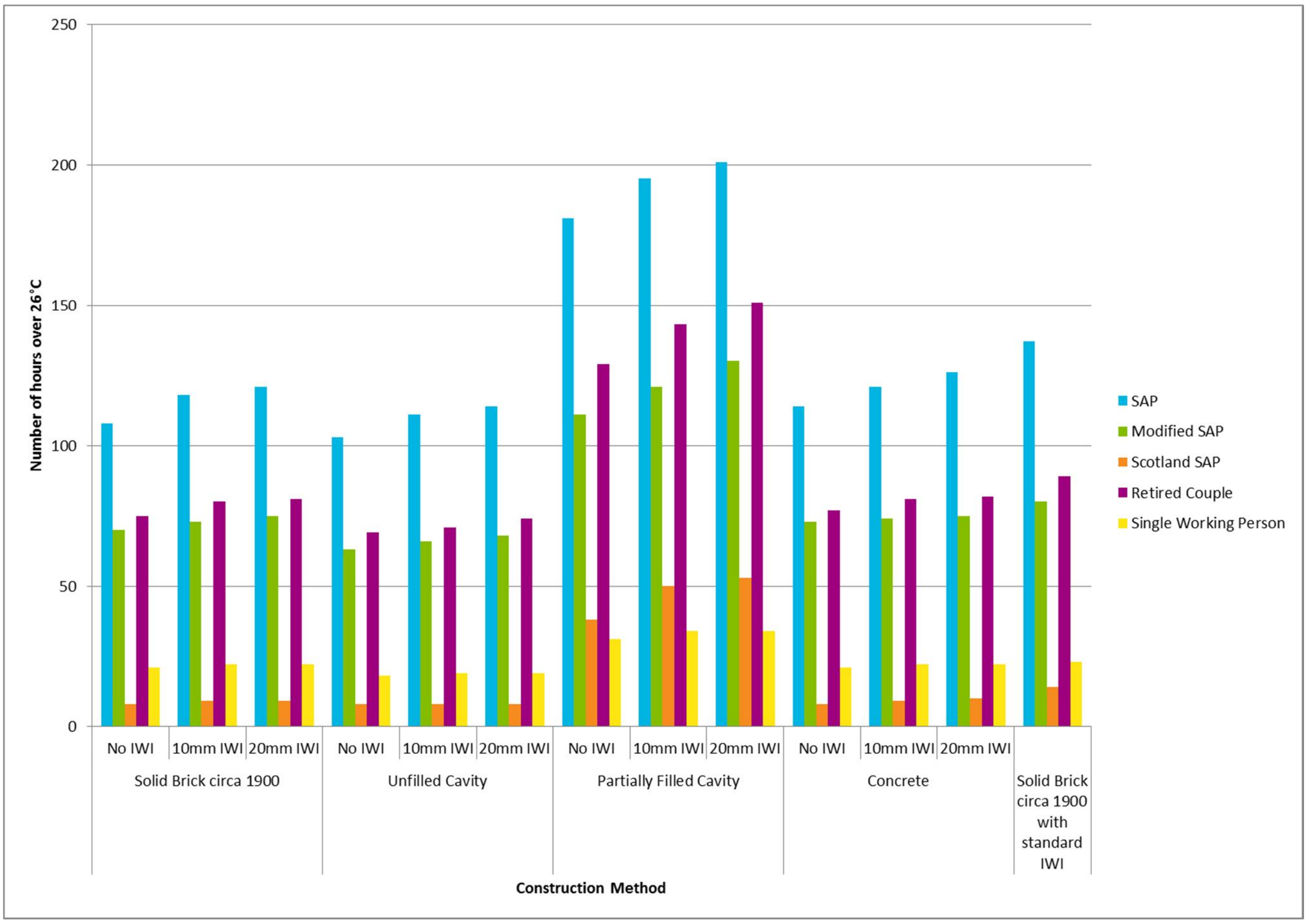


Figure 6: Number of occupied hours the simulated living rooms exceed 26°C.

The calculated number of occupied hours over 26°C is higher than might be expected in most real-world dwellings; this discrepancy is partially caused by changes in occupant behaviour during hot weather. During hot weather real-world occupants are likely to go out more and thus reduce the internal heat gains by removing their bodies from the internal space and by using lights and appliances less; many occupants will also cook less (opting to eat cold meals) and in some cases leave external and internal doors open to increase ventilation.

On average the increase in hours over 28°C in living rooms is 3 occupied hours per year across all scenarios. The greatest increase is from adding 20mm of IWI to the unfilled cavity for the SAP scenario which results in an increase from 91 hours over 28°C, for no IWI, up to 103 hours with 20mm IWI. This increase is small relative to the number of hours that the untreated dwelling is calculated as exceeding 28°C.

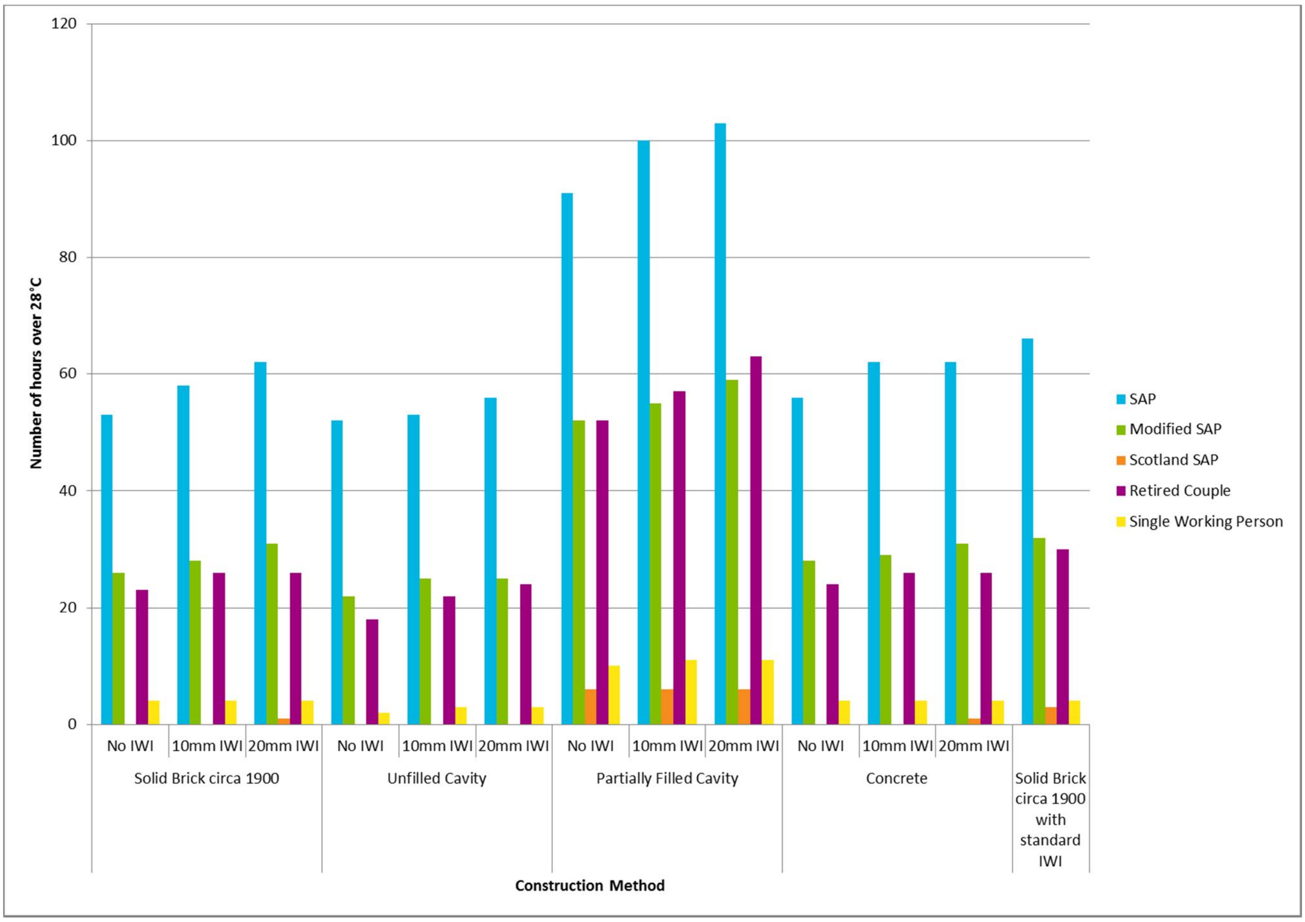


Figure 7: Number of occupied hours the simulated living rooms exceed 28°C.

The simulated master bedrooms were found to be much less prone to overheating; no simulated hours exceeded 28°C and the number of hours over 26°C are much less than for the living room. This is due to the following factors:

- The occupied hours of the bedroom are at night when the outside temperature is generally lower;
- There are less internal gains in the bedroom;
- Bedrooms can benefit from night cooling as it was assumed that windows can be opened at night (unlike in the living room).

In contrast to the living room, the effect of adding thin IWI is sometimes to reduce the number of hours over 26°C; this is due to the effects described on page Figure 5 above. On average the number of occupied hours over 26°C is reduced by 0.2 hours. This ranges from a reduction of 1 occupied hour per year to an increase of 6 occupied hours per year. None of the modelled scenarios were found to exceed 26°C for more than 18 occupied hours per year.

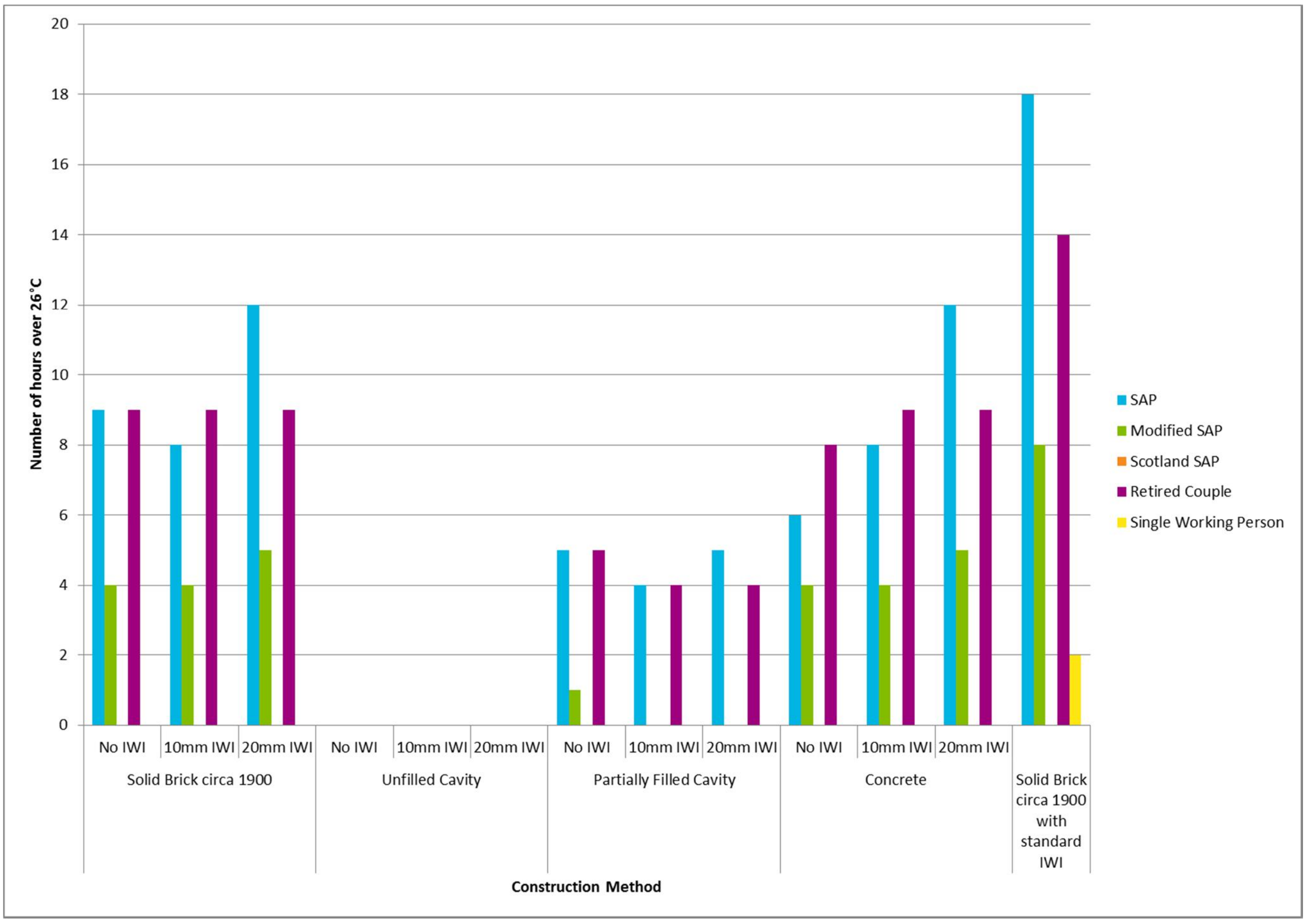


Figure 8: Number of occupied hours the simulated master bedroom exceed 26°C.

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Summary of Findings

04

Summary of Findings

Analysis of the results of this modelling exercise shows that the installation of thin IWI can have the following effects:

– Reduces the calculated space heating requirement compared to where no IWI has previously been installed[6].

  - 10mm IWI was found to achieve a calculated reduction in heat energy requirements of between 4.4% and 10.2%.

  - 20mm IWI was found to achieve a calculated reduction in heat energy requirements of between 6.7% and 15.9%.

  The greatest energy savings are achieved in cases where the initial wall specification is the least insulated and where the occupancy scenarios have the heating on for longer periods.

– A small reduction in the calculated warm-up time of dwellings in the majority of cases. During the warm-up period the calculated increase in temperature achieved by the thin IWI is always less than 1°C. It is thought that this small temperature difference will not be noticeable to most occupants, however further review/research is required to verify this.

– Increases the calculated risk of overheating in living spaces:

  - On average the number of hours that the simulated living rooms exceed 26°C is increased by 7 occupied hours on average per year. This increase is small relative to the absolute number of hours for which this temperature is exceeded without IWI installed.

– Sometimes reduces the calculated risk of overheating in bedrooms:

  - On average the number of hours that the simulated bedrooms exceed 26°C is reduced by 0.2 hours. None of the modelled master bedrooms exceed 26°C for more than 12 occupied hours per year. This change is small relative to the absolute number of hours for which this temperature is exceeded.

The reason dwellings cool down between heating periods is a combination of conductive heat losses and air exchange between inside and outside. This analysis has considered the effects of reducing the conductive heat losses. However, it may that, in some cases, the combined effects of draught proofing and thin IWI may achieve greater savings than the two measures individually. The combination of these two measures may help dwellings to retain heat more effectively and so further reduce their heating requirements.

Conventional IWI has had relatively low take-up. It is expensive, disruptive to install, takes up space and is not accessible for the DIY market. This analysis suggests that thin IWI can achieve up to 57% of the saving of conventional (thicker) wall insulation whilst overcoming many of the challenges that make conventional IWI hard to deploy widely.

It is suggested that some further analysis is undertaken to build on this study:

– Analysis of the effects of applying IWI to all areas except behind coving, skirting and floor-voids.

– Analysis of the combined effects of thin IWI and draught proofing.

– Analysis of the effects of IWI on energy use where the heating is controlled on the basis of dry resultant temperature.

– Analysis of the effects of IWI in dwellings of different sizes and forms.

– Estimate the likely impact on a national scale in terms of reduction in energy use and carbon emissions.

[6] Where conventional IWI is already installed the addition of thin IWI was not assessed.

Appendix

Appendix

Appendix 1. DTS Modelling Process

This section details the process used to produce the DTS model. It discusses the approach taken to produce the geometry, construction build-ups, and occupancy profiles as defined in the report and the settings used to produce the results for analysis.

Building the DTS Model Geometry

The model produced for the DTS was based on analysis of the Cambridge Housing Model data produced by Cambridge Architectural Research Limited for DECC in 2011[7].

A semi- detached house model, as an average representation of the data for such homes presented in the Cambridge Housing Model, was simulated to produce the DTS model. There are approximately 4,000 semi-detached house records in the total of approximately 15,000 CHM records. Analysis of these records produced the following points:

- 90.9% of the houses have two floors (ground and first)
- 11.8% of houses have a room in the roof space
- Average measurements are as follows:
    - Ground floor height = 2.42m
    - First floor height = 2.67m
    - Ground floor area = 51.62m²
    - First floor area = 43.65m²
    - Door area = 4.77m²
    - Window 1 area = 2.56m²
    - Window 2 area = 18.66m²
    - Living room fraction = 0.18

Therefore based on this analysis the following specification was used to produce the semi-detached house model:

- We assumed a two storey building (ground and first floors) with no room in the roof space and the following floor heights:
    - Ground floor = 2.42m
    - First floor = 2.67m
- We assumed the following floor areas
    - Ground floor 45m² with a living room area of 18m² (approximately 20% of the total floor area of the house) and containing the following rooms:
        - Living room
        - Kitchen/dining room
        - Hall and stairs with under stair cupboard
    - First floor 45m² and containing the following rooms:
        - Bedroom 1 (master bedroom)
        - Bedroom 2
        - Bedroom 3
        - Bathroom with separate toilet
        - Landing space and stairs
- We assumed the following external façade elements:
    - External doors have a total area of approximately 5m² (one at the front of 3.15m² and one at the side of 1.91m²)
    - External window areas:
        - Front wall approximately 9m²

[7] https://www.gov.uk/government/statistics/cambridge-housing-model-and-user-guide

  - Side wall approximately $2.5m^2$
  - Back wall approximately $9m^2$
- o Simple ridged roof with insulation at the ceiling level of the first floor

The following figures show the shape of the semi-detached house without its adjacent neighbour, and the internal layouts of the ground and first floors. The internal layouts show the templates assigned to each room at the start of the study to enable appropriate heat loss calculations to be performed (discussed in more detail in later sections of the report).

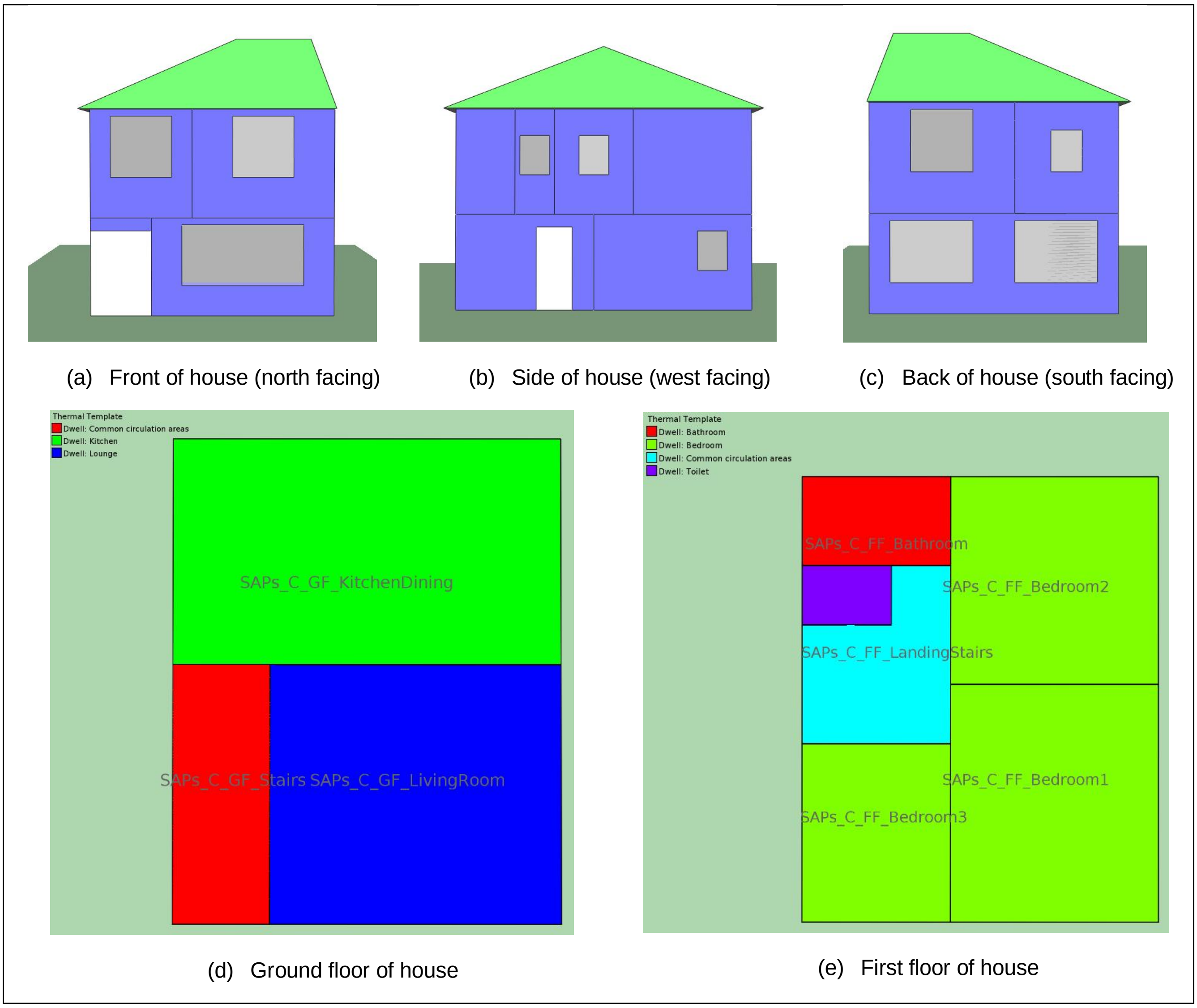


Figure 9: Images 9(a) to 9(c) show the external façade of the modelled semi-detached house, images 9(d) and 9(e) show the internal layout of the semi-detached house and the applied thermal template.

Shading

Typical semi-detached houses are located in suburban areas and as such are partially shaded by surrounding houses. To take account of this effect the modelled dwellings have notional dwellings located around them to mimic the shading of a typical suburban area. The distance between *neighbouring* houses was assumed to be 7.5m based on an example semi-detached house and the space between being used for driveways and paths. The distance between houses in-front and behind the study house was assumed to be 20m. This is to account for either:

- Back to back rows of houses which have 10m length of garden each;
- A sample road, with pedestrian walk ways and small front gardens between each row.

Constructions Options

The following table details the agreed U-values of the different construction methods investigated in this study and the associated U-values for windows, floors, roofs and doors, as well as the assumed G-value of all glazing in the modelled house.

Archetype	U-value (W/m²K)				G-value
	Wall	Roof	Floor	Windows & Doors	Windows
Solid brick circa 1900	1.70	0.26	1.20	3.10	0.76
Unfilled cavity	1.40	0.26	1.20	3.10	0.76
Partial fill	0.60	0.26	0.51	3.10	0.76
Concrete construction	1.30	0.26	1.20	3.10	0.76
Solid brick circa 1900 with standard IWI	0.50	0.26	1.20	3.10	0.76

Table 9: Table of external fabric U-values and glazing G-values.

All the windows are assumed to be double glazed units with the following specification:

- U-value 3.10W/m²K
- G-value 0.76
- 6mm panes with 12mm argon filled gap
- Wooden frame which accounts for 10% of total area
- Visible light transmittance 0.71
- Internal curtains/blinds applied which have the following properties:
    - They are closed when the incident radiation on the window is greater than 150W/m²
    - They are opened when the incident radiation on the windows drops below 100W/m²
    - They are assumed to have a shading coefficient of 0.48
    - They are assumed to have a short-wave radiant fraction of 0.625

External doors are assumed to be simple plywood construction.

The following table provides a more detailed description of the constructions for each of the above options, and the assumed constructions for other elements of the houses (e.g. party walls, internal partitions, etc.).

Construction	Description	U-value (W/m²K)
Solid brick wall circa 1900	Two 105mm brick layers with small 5mm cavity between them and plasterboard internal wall finish	1.70
Unfilled cavity wall	External brick layer of 105mm with 100mm cavity to internal brickwork of 105mm with dense internal plaster finish	1.40
Partially filled cavity wall	External brick layer of 105mm with 50mm cavity and 50mm insulation to internal brickwork of 105mm with internal plasterboard finish	0.60
Concrete wall (no fines concrete construction)	214mm thick concrete with internal plasterboard to finish	1.30
Solid brick wall circa 1900 with current typical internal wall insulation	Two 105mm brick layers with small 5mm cavity between them, internal insulation board with plasterboard finish	0.50
Roof (applied to ceiling of first floor)	Timber boards with glass fibre insulation and plasterboard to ceiling of the first floor	0.26

Construction	Description	U-value (W/m²K)
Ground floor (all bar partially filled cavity wall houses)	Ground with a cavity to insulation and chipboard flooring	1.20
Ground floor (partially filled cavity walls only)	Cast concrete floor with insulation and chipboard flooring above	0.51
Internal floors (between ground and first floor)	Plasterboard ceiling, with cavity and timber flooring above. Carpet finish on first floor	1.07
Internal walls (partially filled cavity wall houses only)	Plasterboard with 100mm cavity to plasterboard	1.79
Internal walls (all bar partially filled cavity wall houses)	Dense plaster either side of 105mm breeze block	2.10
Party walls [1] for unfilled and partially filled cavity wall houses only	Assumed to be an open and unfilled cavity (in line with research by Leeds Beckett University and current SAP conventions) with plasterboard and breeze block walls either side	0.50

[Note 1] All other party walls are assumed to be to adiabatic, and therefore no specific construction is required

Table 10: Table of opaque constructions including description of construction makeup and U-value.

The infiltration rate has been modelled as 15m³/m²/hr @ 50Pa, for the purposes of modelling this is deemed to be equivalent to 0.522ACH.

In addition to these constructions, two options of thin internal wall insulation were simulated - 10mm and 20mm. Based on a commercially available thermal lining product, the specification of the thin internal wall insulation was assumed to be:

- Thermal conductivity – 0.0515 W/mK
- Density – 186.4 kg/m³
- Specific heat capacity – 2,000 J/kgK

When applied in conjunction with the external wall constructions detailed above the U-values reduce, as shown in the below table.

External Wall Construction	U-Value (W/m²K)		
	Without thin IWI	With 10mm thin IWI	With 20mm thin IWI
Solid brick circa 1900	1.70	1.28	1.03
Unfilled cavity	1.40	1.10	0.91
Partially filled cavity	0.60	0.54	0.49
Concrete construction (no fines concrete)	1.30	1.04	0.86
Solid brick circa 1900 with standard IWI	0.50 [Note 1]	N/A	N/A

[Note 1] The U-value indicated includes the standard ‘thick’ IWI and no additional ‘thin’ IWI

Table 11: Table of external wall U-values with no thin IWI, 10mm of thin IWI, and 20mm of thin IWI calculated using BRE U-value calculator version 2.04b.

Heat Loss and Radiator Sizing

Before applying the occupancy profiles and running the simulations, a heating system needs to be applied which provides an appropriately sized heat source for each of the heated rooms in the house. This is because each room will have a radiator fitted which has been sized to meet the heating demand of the room, and account for the heat loss through the associated external envelope. It was assumed that the size of this radiator has not been changed since each building was first built, and that it will not be changed when the thin IWI is applied. In the case of the solid brick with conventional IWI it was assumed that the radiators have been unchanged since the installation of the IWI, i.e. they have been sized based on solid brick walls with no insulation.

To size each radiator a heat loss simulation was run for a sample house with each of the construction methods stated in the previous section. The following specification was used for each room in the house (regardless of construction method).

Room	Infiltration rate (ACH)	Heated?	Heating Set Point (°C)
Bedroom	1	Yes	21
Living room	1	Yes	21
Kitchen/Dining room	3	Yes	21
Entrance hall/stairs	4	Yes	21
Landing/stairs	4	No	N/A
Toilet	3	No	N/A
Bathroom	3	Yes	21

Table 12: Heating settings for each room type in the house.

As the simulations included both a Manchester and Edinburgh weather tape, the heat loss simulation was run twice, once with each weather tape and with the following outdoor winter design temperature:

- Manchester -5°C
- Edinburgh -6°C

The steady state heating load for each of the heated rooms was then extracted, and increased by a further 10% (as an approximate way to account for additional losses due to thermal mass). The increased steady state heat load for each room was then compared to a list of standard radiator outputs and the next radiator size up selected for each room. The following table shows the size of the selected radiator in each room, for each construction method, for both the Manchester and Edinburgh weather tapes.

Weather Tape	External Wall Type	Radiator Size for each Room (W) – assumed that the unheated rooms have no radiators						
		Living Room	Hall and Stairs	Kitchen and Dining Room	Bathroom	Bedroom 1	Bedroom 2	Bedroom 3
Manchester	**Solid brick circa 1900**	1687	1499	3557	937	1124	1124	1124
	Unfilled cavity	1778	1499	3557	937	1312	1124	1031
	Partially filled cavity	1312	1124	2856	750	1031	1031	750
	Concrete walls	1687	1499	3557	843	1031	1031	1031
	Solid brick circa 1900 with current IWI	1687	1499	3557	937	1124	1124	1124
Edinburgh	**Solid brick circa 1900**	1778	1499	3557	1031	1124	1124	1124
	Unfilled cavity	1922	1499	3557	937	1312	1312	1031
	Partially filled cavity	1499	1312	3201	750	1031	1031	843
	Concrete walls	1687	1499	3557	937	1124	1124	1031
	Solid brick circa 1900 with current IWI	1778	1499	3557	1031	1124	1124	1124

Table 13: Selected radiator size for each room in each house based on the heating set points, construction method, and location.

Occupancy Profiles – Overview

It was agreed that 5 different combinations of occupancy and location would be included in the study. These are detailed below. In the profiles, the internal gains are described as ‘on’ or ‘off’ or ‘S’, where ‘S’ represents some level of reduced ‘on’ (e.g. reduced window openings overnight, reduced people gains at night – assuming they are asleep).

- A standard SAP assessment profile, using current SAP assumptions for internal gains and using them to produce a set of DTS internal gain profiles.

	Variable	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-00
Weekday	Occupancy	S	S	S	S	S	S	S	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	S	S
	Lights	off	off	off	off	off	off	off	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	off	off
	Appliances	off	off	off	off	off	off	off	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	off	off
	Heating	off	off	off	off	off	off	off	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	off	off
	Windows	S	S	S	S	S	S	S	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	S	S
Weekend	Occupancy	S	S	S	S	S	S	S	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	S
	Lights	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
	Appliances	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
	Heating	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
	Windows	S	S	S	S	S	S	S	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	S

Table 14: Profiles for occupancy, lights, appliances, heating and windows, for weekdays and weekends for the SAP occupancy profile.

- A standard SAP assessment profile based in Scotland, Edinburgh. All profiles are the same as shown in Table 14.

- A modified SAP profile which was based on the findings of the Energy Follow-up Survey[8]. This Survey identified a number of differences between the current SAP assumptions, specifically the change in heating profile on weekends versus weekdays

	Variable	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-00
Weekday	Occupancy	S	S	S	S	S	S	S	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	S	S
	Lights	off	off	off	off	off	off	off	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	off	off
	Appliances	off	off	off	off	off	off	off	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	off	off
	Heating	off	off	off	off	off	off	off	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	off	off
	Windows	S	S	S	S	S	S	S	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	S	S
Weekend	Occupancy	S	S	S	S	S	S	S	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	S
	Lights	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
	Appliances	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
	Heating	off	off	off	off	off	off	off	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	off	off
	Windows	S	S	S	S	S	S	S	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	S

Table 15: Profiles for occupancy, lights, appliances, heating and windows, for weekdays and weekends for the modified SAP occupancy profile.

8 https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011

- A profile set for a assumed retired couple

	Variable	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-00
Weekday	Occupancy	S 2	S 2	S 2	S 2	S 2	S 2	S 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	S 2	S 2
	Lights	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off
	Appliances	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off
	Heating	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off
	Windows	S	S	S	S	S	S	S	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	S	S
Weekend	Occupancy	S 2	S 2	S 2	S 2	S 2	S 2	S 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	on 2	S 2	S 2
	Lights	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off
	Appliances	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off
	Heating	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off
	Windows	S	S	S	S	S	S	S	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	S	S

Table 16: Profiles for occupancy, lights, appliances, heating and windows, for weekdays and weekends for the retired couple occupancy profile.

- A profile set for a assumed single working person

	Variable	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-00
Weekday	Occupancy	S	S	S	S	S	S	S	on	off	off	off	off	off	off	off	off	off	off	on	on	on	on	S	S
	Lights	off	off	off	off	off	off	off	on	off	off	off	off	off	off	off	off	off	off	on	on	on	on	off	off
	Appliances	off	off	off	off	off	off	off	on	off	off	off	off	off	off	off	off	off	off	on	on	on	on	off	off
	Heating	off	off	off	off	off	off	off	on	off	off	off	off	off	off	off	off	off	off	on	on	on	on	off	off
	Windows	S	S	S	S	S	S	S	on	off	off	off	off	off	off	off	off	off	off	on	on	on	on	S	S
Weekend	Occupancy	S	S	S	S	S	S	S	on	on	on	off	on	on	off	off	off	off	on	on	on	on	on	S	S
	Lights	off	off	off	off	off	off	off	on	on	on	off	on	on	off	off	off	off	on	on	on	on	on	off	off
	Appliances	off	off	off	off	off	off	off	on	on	on	off	on	on	off	off	off	off	on	on	on	on	on	off	off
	Heating	off	off	off	off	off	off	off	on	on	on	off	on	on	off	off	off	off	on	on	on	on	on	off	off
	Windows	S	S	S	S	S	S	S	on	on	on	off	on	on	off	off	off	off	on	on	on	on	on	S	S

Table *17*: Profiles for occupancy, lights, appliances, heating and windows, for weekdays and weekends for the single working person occupancy profile.

The rest of this section describes in more detail how these profiles have been applied to each respective room in the semi-detached house.

Occupancy Profiles – Heating

The different occupancy profiles have been assumed to use one of two different heating seasons and heating set points, which are shown in the table below.

Occupancy Profile	Heating Set Point (Living Room) (°C)	Heating Set Point (All other heated rooms) (°C)	Heating Season
SAP	21.0°C	18.0°C	January to April and September to December
SAP in Scotland			
Retired Couple			
Modified SAP	20.2°C [1]	19.1°C [1]	January to April and mid-October to December [Note 1]
Single Working Person			

[Note 1] The heating set points and seasons are based on the Energy Follow-up Survey[9].

Table 18: Heating set points and season for each occupancy profile option.

Occupancy Profiles – People

The following numbers of people have been assumed in each of the occupancy profiles:

Occupancy Profile	Number of Occupants in house	Details
SAP	2.63	Calculated using Table 1b from SAP 2012
SAP in Scotland	2.63	Assumed to be the same as the SAP profile
Modified SAP	2.63	Assumed to be the same as the SAP profile
Retired Couple	2.00	Based on discussions with DECC around occupancy profiles
Single Working Person	1.00	Based on discussions with DECC around occupancy profiles

Table 19: Number of people assumed in each occupancy profile and details how that number has been determined.

The occupants are assumed to make use of the following rooms in the house:

- The master bedroom and second bedroom (only in the SAP related profiles)
- The bathroom
- The living room
- The kitchen and dining room

The occupancy profiles assume that people get up from the bedrooms and make use of the bathroom and kitchens first each morning before using the living room. In the evenings this order is reversed once they have used the kitchen to prepare an evening meal. On weekends the kitchen is also assumed to be used to produce a lunchtime meal.

The retired couple are assumed to make use of the living room for most of the day, and are assumed to have the same routine all week.

The single working person is assumed to spend an hour out of the house in the mornings on the weekend, which is assumed as time to run weekly errands such as shopping, before coming home to spend a couple of hours making lunch and using the living room. They are then assumed to leave the house for 4 hours in the afternoon; this is assumed for social activities and an active lifestyle.

[9] https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011

The heat gains of the occupants are taken from CIBSE Guide A, with the heat generation (W/m²) per person based on varying activities. These gains were then used to determine the total heat gains from the occupants at different points in the day, e.g. sleeping heating gains from the occupants at night, standing heat gains while in the kitchen or bathroom.

For the SAP and SAP in Scotland profiles, the total heat gains have been adjusted to provide approx. 1,440Wh/day/person based on Table 5a of SAP 2012 which assumes 60W per person per hour.

Occupancy Profiles – Lights

The lighting used in the SAP related profiles (SAP and SAP in Scotland) are calculated based on the equations in section L1 of SAP 2012. Calculations assumed the previously reported number of occupants, and that only low energy lighting fixtures are installed. The calculated lighting gain was then assumed to be the total lighting gains for the whole day in the house. This was then divided up and applied to each occupied room in the house, assuming that the lights are only on in the rooms which are occupied at any point in time during the day.

For the other occupancy profiles (Modified SAP, Retired Couple, and Single Working Person) the lighting gains are based on a total lighting power of 40W per room, again only low energy lighting fixtures, and the assumed time each room's lights are on. This is based on the occupancy profiles for each room and the time of day it is occupied.

Based on these calculations and profiles the total lighting gains for each profile are shown in the following table:

Occupancy Profile	Total Daily Lighting Gains Simulated (kWh/day)	Total Annual Lighting Gains Simulated (kWh/year)
SAP	1.53	556.9
SAP in Scotland	1.53	556.9
Modified SAP	0.43	157.3
Retired Couple	0.60	218.8
Single Working Person	0.26	93.8

Table 20: DTS lighting gains for each occupancy profile.

Occupancy Profiles – Equipment

The equipment gains for each occupancy profile option are based on the following initial assumptions:

Occupancy Profile	Details
SAP	Calculated using section L2 from SAP 2012 for appliances and L3 for cooking
SAP in Scotland	Assumed to be the same as the SAP profile
Modified SAP	Taken from CIBSE TM37, tables 5.6, 5.7 and 5.8
Retired Couple	Taken from CIBSE TM37, tables 5.6, 5.7 and 5.8
Single Working Person	Taken from CIBSE TM37, tables 5.6, 5.7 and 5.8

Table 21: Equipment gain assumptions for each occupancy profile.

For the profiles which use equipment gains from the CIBSE TM37 tables the following equipment has been assumed for each profile, with the associated assumed operations.

Appliance	Occupancy Profile		
	Modified SAP	Retired Couple	Single Working Person
Television – LCD (up to 60cm)	2 units, on 3 hours per day	2 units, on 7 hours per day	2 units, on 2 hours per day
Digital TV adaptor box	On all the time	On all the time	On all the time
Microwave oven	Used 20 minutes per day	Used 30 minutes per day	Used 15 minutes per day
Refrigerator – A rated	On all the time	On all the time	On all the time
Freezer – upright, A rated	On all the time	On all the time	On all the time
Washing machine – A rated	4 loads per week	4 loads per week	2 loads per week
Condensing tumble dryer – A rated	3 loads per week, only in Winter[1]	3 loads per week, only in Winter[1]	1 loads per week, only in Winter[1]
Oven – A rated	Used 1 hour per day	Used 1 hour per day	Used 30 minutes per day
Hobs – gas	Used 1 hour per day	Used 1 hour per day	Used 30 minutes per day
Laptop	Used 3 hours per day	Used 5 hours per day	Used 2 hours per day
DVD Player	Used 2 hours per day	Used 2 hours per day	Used 2 hours per day

Note [1] Tumble dryers are assumed to be on during the winter, based on the heating seasons of the occupancy profile

Table 22: Appliances used in the Modified SAP, retired couple, and single working person profiles with descriptions of time/number of users per appliance.

All of the appliances are assumed to be in the kitchen with the exception of the following items:

- 1 of the 2 televisions
- Digital TV adaptor box
- Laptop
- DVD player

In all occupancy profiles there is assumed to be a level of equipment gains throughout the day to account for items like the fridge, freezer and digital TV adaptor box being on at all times. Other equipment is assumed to be turned on when the room is occupied and off when unoccupied. It has also been assumed that more appliances are used in the evening than the morning with only a small increase in kitchen power consumption first thing in the morning for making breakfast, and on the weekends at lunch time.

Based on these calculations and profiles the total equipment gains for each profile are shown in the following table.

Occupancy Profile	Total Daily Equipment Gains Simulated (kWh/week)	Total Annual Equipment Gains Simulated (kWh/year)
SAP	Approx. 69.5	3,606.7
SAP in Scotland	Approx. 69.5	3,606.7
Modified SAP	Approx. 31.7	1,526.9
Retired Couple	Approx. 36.3	1,791.7
Single Working Person	Approx. 21.3	1,084.6

Table 23: DTS equipment gains for each occupancy profile.

Occupancy Profiles – Windows and Ventilation

It is assumed that the windows will only be opened during occupied hours. Ground floor windows have been modelled as closed overnight; first floor windows are modelled as being openable at night but to a limited distance. The following rooms in each house have been assumed to have openable windows:

- Living room – only while occupied, and shut overnight
- Kitchen and dining room – only while occupied and shut overnight
- Bedrooms – only if occupied, and at a reduced level overnight
- Bathroom – only while occupied and at a reduced level overnight

The windows are assumed to start opening when the ambient temperature in the room reaches 23°C and is assumed to be fully opened when the ambient temperature reaches 26°C. All windows are assumed to be top hung and open to an angle of 10° which provides an opening area of 17% of the window area. At night the windows which can be left on a reduced opening are assumed to be left open at 10% of the total opening, so providing an opening area of 1.7% of the window area.

These window opening assumptions are different to those embedded in the SAP calculation method; SAP offers four options:

1. Trickle ventilation only
2. Slightly open (50mm)
3. Fully open
4. Fully open half the time

For two storey dwellings, such as that used in this analysis, the 4th option is normally selected. However it is widely agreed that this assumption is unrealistic as it implies that windows will be left fully open at times when the dwelling is unoccupied and that ground floor windows may be left open overnight. The window opening assumptions used in this analysis are deemed to be a more realistic representation of how occupants open and close windows in reality.

Based on the assumptions used in SAP 2012 the whole house is assumed to have a continuous mechanical extract rate of 0.5 air changes per hour. This is to account for the assumed mechanical extract ventilation systems which are used in the following rooms:

- Kitchen extract fan and cooking extract hood
- Bathroom extract fan
- Toilet extract fan

As SAP does not distinguish between individual rooms, it assumes that this extract ventilation is applied to the whole house volume. The same assumption was applied to the semi-detached house modelled in this study.

The overheating risk calculated in SAP uses a simplified monthly heat balance calculation method. Dynamic Simulation and Overheating Risk Assessment analysis requires hourly data. The external temperature data used in SAP for overheating assessment is the long term average weather data for the degree day region the property is located in. The CIBSE Test Reference Year (TRY) weather files for Manchester and Edinburgh (hourly data) were used in this study. These data are similarly based on the long-term average weather over a 20-year period.

Appendix 2. Warm-up Time Graphs

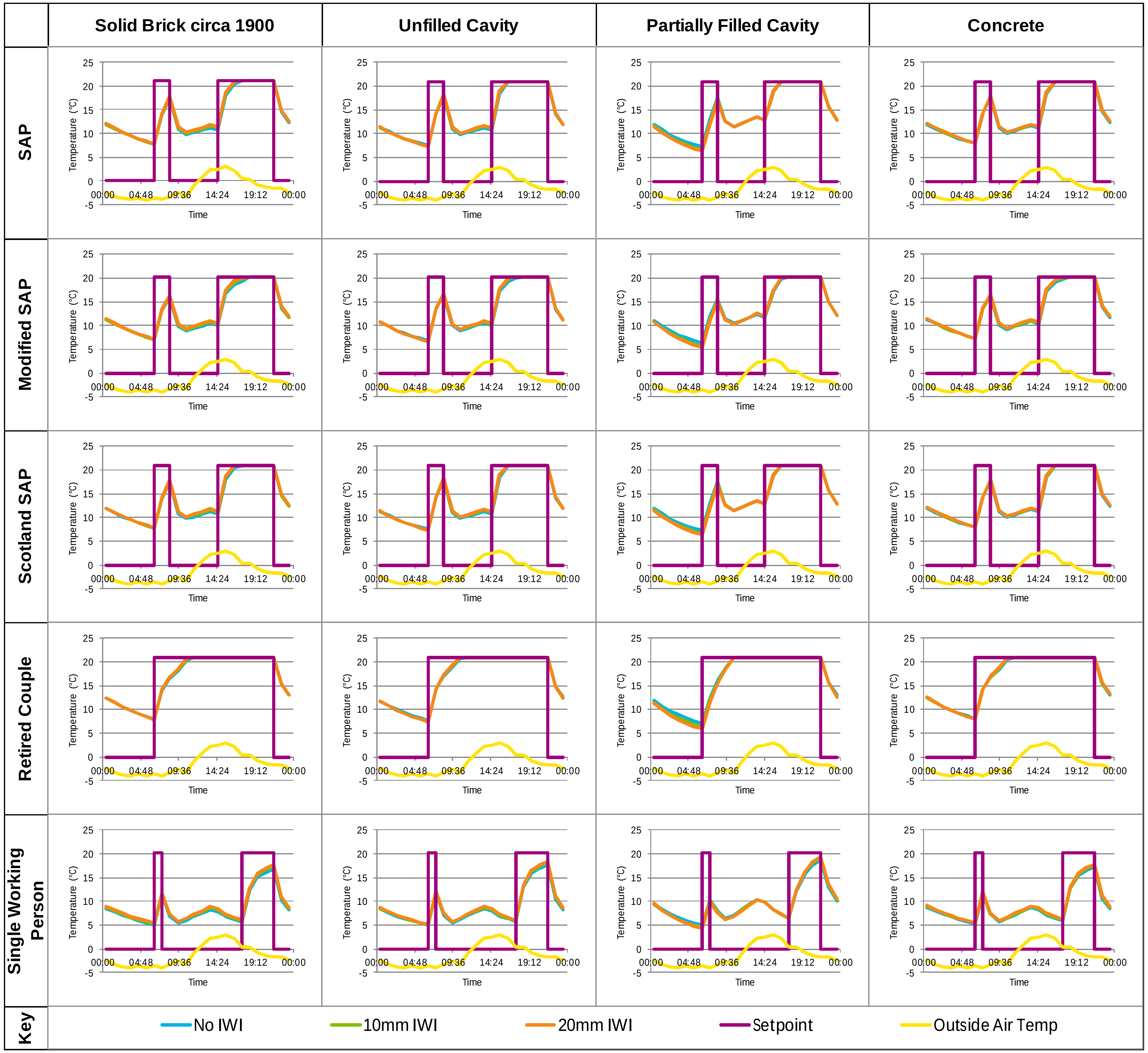


Figure 10: Livingroom warm-up graphs.

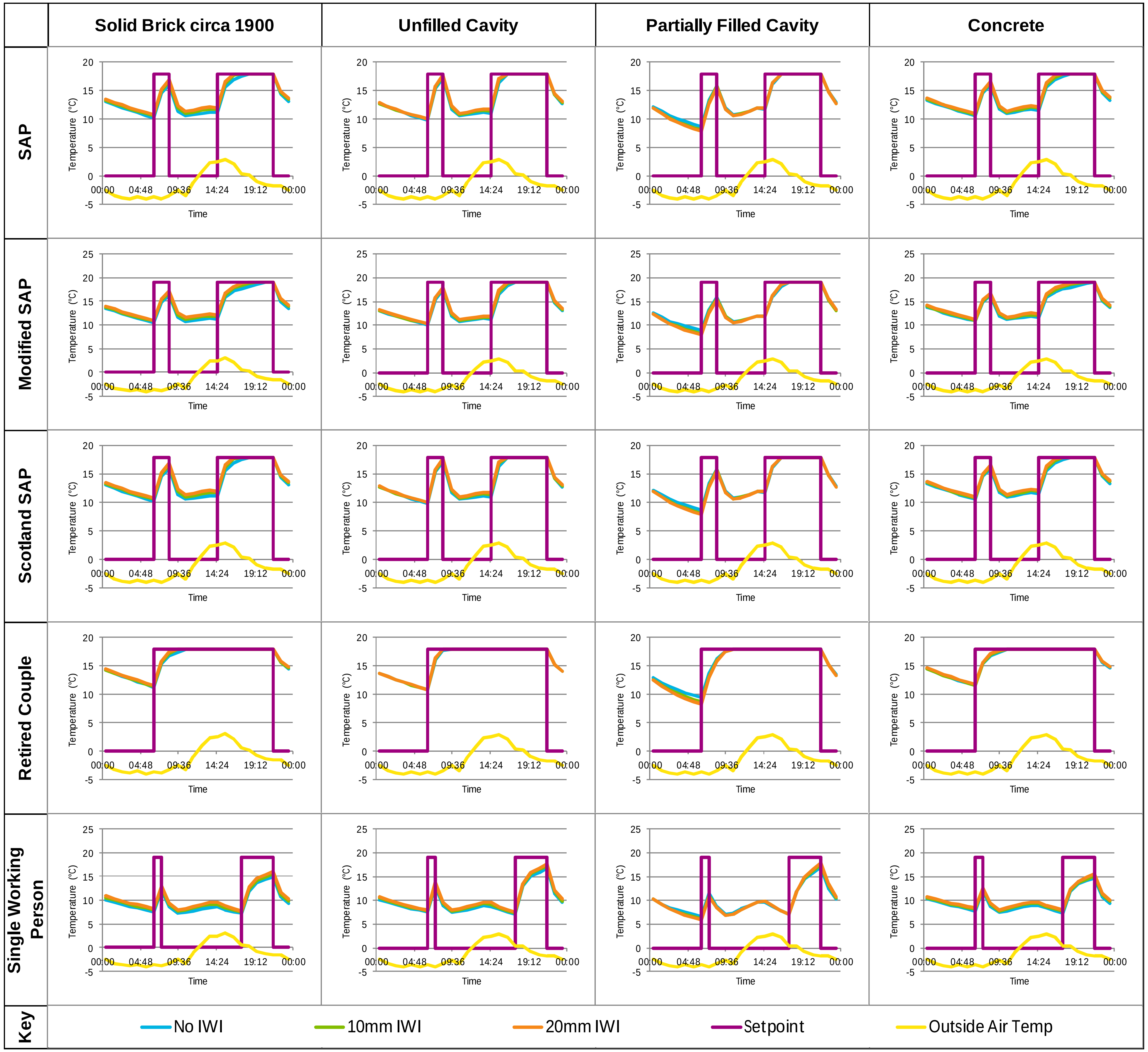
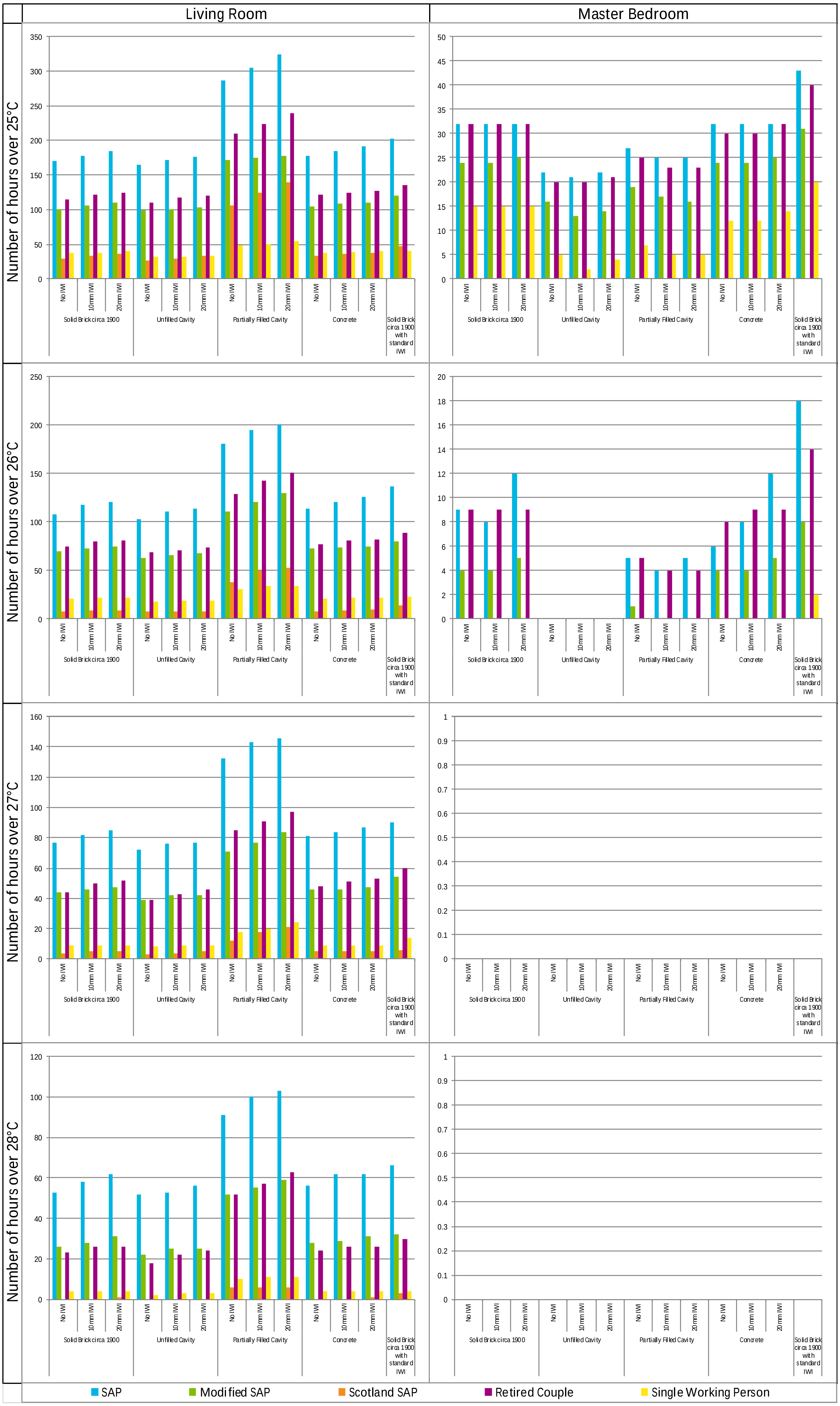


Figure 11: Master bedroom warm-up graphs.

Appendix 3. Overheating Risk Assessment Graphs



The following tables were used to produce the above graphs for the living rooms.

Occupancy Profile	Number of occupied hours over 25°C												
	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	
SAP	171	178	185	165	172	176	287	305	325	178	184	191	203
Modified SAP	100	106	110	99	101	104	172	175	177	105	109	111	120
Scotland SAP	30	34	36	26	29	33	106	125	140	34	36	38	48
Retired Couple	114	122	125	111	117	120	210	223	239	121	125	127	136
Single Working Person	38	38	40	32	32	33	49	50	55	38	39	40	41

Table 24: Number of hours with an internal air temperature greater than 25°C for each living room with each combination of occupancy profile and construction method.

Occupancy Profile	Number of occupied hours over 26°C												
	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	
SAP	108	118	121	103	111	114	181	195	201	114	121	126	137
Modified SAP	70	73	75	63	66	68	111	121	130	73	74	75	80
Scotland SAP	8	9	9	8	8	8	38	50	53	8	9	10	14
Retired Couple	75	80	81	69	71	74	129	143	151	77	81	82	89
Single Working Person	21	22	22	18	19	19	31	34	34	21	22	22	23

Table 25: Number of hours with an internal air temperature greater than 26°C for each living room with each combination of occupancy profile and construction method.

Occupancy Profile	Number of occupied hours over 27°C												
	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	
SAP	77	82	85	72	76	77	132	143	146	81	84	87	90
Modified SAP	44	46	47	39	42	42	71	77	84	46	46	47	54
Scotland SAP	4	5	5	3	4	5	12	18	21	5	5	5	6
Retired Couple	44	50	52	39	43	46	85	91	97	48	51	53	60
Single Working Person	9	9	9	8	9	9	18	20	24	9	9	9	14

Table 26: Number of hours with an internal air temperature greater than 27°C for each living room with each combination of occupancy profile and construction method.

Occupancy Profile	Number of occupied hours over 28°C												
	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	
SAP	53	58	62	52	53	56	91	100	103	56	62	62	66
Modified SAP	26	28	31	22	25	25	52	55	59	28	29	31	32
Scotland SAP	0	0	1	0	0	0	6	6	6	0	0	1	3
Retired Couple	23	26	26	18	22	24	52	57	63	24	26	26	30
Single Working Person	4	4	4	2	3	3	10	11	11	4	4	4	4

Table 27: Number of hours with an internal air temperature greater than 28°C for each living room with each combination of occupancy profile and construction method.

The following tables were used to produce the above graphs for the master bedroom.

Occupancy Profile	Number of occupied hours over 25°C												
	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	
SAP	32	32	32	22	21	22	27	25	25	32	32	32	43
Modified SAP	24	24	25	16	13	14	19	17	16	24	24	25	31
Scotland SAP	0	0	0	0	0	0	0	0	0	0	0	0	0
Retired Couple	32	32	32	20	20	21	25	23	23	30	30	32	40
Single Working Person	15	15	15	5	2	4	7	5	5	12	12	14	20

Table 28: Number of hours with an internal air temperature greater than 25°C for each master bedroom with each combination of occupancy profile and construction method.

Occupancy Profile	Number of occupied hours over 26°C												
	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	
SAP	9	8	12	0	0	0	5	4	5	6	8	12	18
Modified SAP	4	4	5	0	0	0	1	0	0	4	4	5	8
Scotland SAP	0	0	0	0	0	0	0	0	0	0	0	0	0
Retired Couple	9	9	9	0	0	0	5	4	4	8	9	9	14
Single Working Person	0	0	0	0	0	0	0	0	0	0	0	0	2

Table 29: Number of hours with an internal air temperature greater than 26°C for each master bedroom with each combination of occupancy profile and construction method.

Occupancy Profile	Number of occupied hours over 27°C												
	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	
SAP	0	0	0	0	0	0	0	0	0	0	0	0	0
Modified SAP	0	0	0	0	0	0	0	0	0	0	0	0	0
Scotland SAP	0	0	0	0	0	0	0	0	0	0	0	0	0
Retired Couple	0	0	0	0	0	0	0	0	0	0	0	0	0
Single Working Person	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 30: Number of hours with an internal air temperature greater than 27°C for each master bedroom with each combination of occupancy profile and construction method.

Occupancy Profile	Number of occupied hours over 28°C												
	Solid Brick circa 1900			Unfilled Cavity			Partially Filled Cavity			Concrete			Solid Brick circa 1900 with standard IWI
	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	No IWI	10mm IWI	20mm IWI	
SAP	0	0	0	0	0	0	0	0	0	0	0	0	0
Modified SAP	0	0	0	0	0	0	0	0	0	0	0	0	0
Scotland SAP	0	0	0	0	0	0	0	0	0	0	0	0	0
Retired Couple	0	0	0	0	0	0	0	0	0	0	0	0	0
Single Working Person	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 31: Number of hours with an internal air temperature greater than 28°C for each master bedroom with each combination of occupancy profile and construction method.

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