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# THE SIMULATED THERMAL PERFORMANCE OF A TWO-STOREY EARTH SHELTERED HOUSE WITH SINGLE ADULT OCCUPANCY IN A TEMPERATE CLIMATE

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## ABSTRACT

This paper discusses the results of a dynamic simulation study on the coldest day of the climatic test year 1985 for a semi-detached earth sheltered house on two storeys and with three bedrooms. The earth sheltered house has no form of active space heating other than a mechanical ventilation heat recovery system and relies solely on stabilising effects of the earth, passive solar gain and heat losses from appliances and occupation from one adult. The results of the resultant internal temperatures in the ground floor lounge and first floor master bedroom are compared with the external temperature. There are seven models in the analysis split into two design groups with a common 1st floor south facing external wall configuration. The two common first floor design configurations include an insulated external wall and an insulated buffer wall combined with an insulated Trombé wall. Within each group of three models the effects of three earth covers (1500, 750 and 250 mm) on the internal temperatures are analysed. Group 1 also test the effects of zero earth cover on the internal conditions. In addition, each model analyses the effect of single adult on the internal conditions. It is seen that the greatest earth cover significantly improves the internal temperatures on both floors, but that often these temperatures do not meet CIBSE's (CIBSE 1986), recommended design temperatures for habitable rooms.

## KEYWORDS

Earth Sheltered Houses, Passive Solar Design, Dynamic Simulation, Zero Heating

## 1. INTRODUCTION

Earth sheltered houses (esh units) are considered a relatively sustainable form of housing and according to Littlewood (1998i, 1998ii), Baggs (1991), Sterling (1981) and Carpenter (1994), this form of housing can reduce the need for active space heating, if a number of features are used. These features include building the house into an earth banking, which is well drained, and sheltering the roof and walls with earth of between 250, 500 and 1500 mm thickness (White 1998, Littlewood 2001, and Carpenter 1994). Other features include designing the house around passive solar design principles. These include orientating exposed high performance (1.5 $W/m^2\ ^oC$) windows within 30 degrees of South, appropriately positioned super-insulation (0.2 to 0.13 $W/^2\ ^oC$), mechanical ventilation heat-recovery (MVHR) systems, passive sunspace and a massive structure for thermal storage. Most of the writers (Baggs 1991, Sterling 1981, and Carpenter 1994) on esh units do not agree on the optimum depth of earth cover, or whether a passive sunspace is needed in order to eliminate the need for active space, whilst providing comfortable internal temperatures between 18.0 and 23.0 $^{o}$C, for the UK climate.

## 1.1 Computer Model And House Design

Figure 1.1 and 1.2 below illustrate the ground floor and first floor plan of a semi-detached two-storey earth sheltered house (esh unit) designed by Littlewood (2001). Littlewood's esh unit was designed as part of a pair of semi-detached esh units, so that a comparison could be made between single adult occupancy and family (two adults and two children) occupancy. This paper however, will focus on analysing the affects of single adult occupancy on the internal resultant temperatures. The esh unit does not include any active space heating, but relies on passive solar gain, heat losses from appliances and occupancy and the utilisation of a MVHR system. Figures 1.3, 1.4 and 1.5 below, illustrate how external air is pre-warmed by the main conservatory for the ground floor rooms, and by the kitchen conservatory for the first floor rooms on the winter test day.

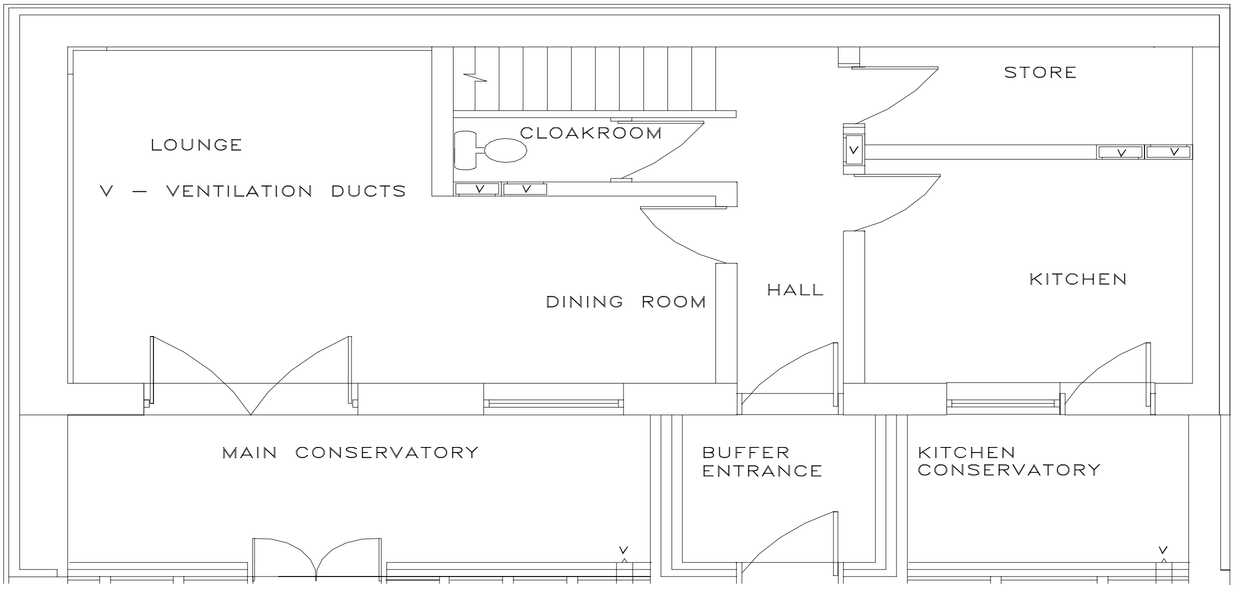


**Figure 1.1: Ground Floor Plan For One Of The Pair Of Semi-Detached Two-Storey Earth Sheltered Houses**

Seven computer models were created in Tas Lite (see Table 1.1) of the esh units, to test the affect of four variations in earth cover, including none, and the two first floor design options, on the internal resultant temperatures in the lounge (zone 1) and master bedroom (zone 21), compared with the external temperature. Models A to C and S do not include a passive solar collector to the first floor exposed external wall, facing due south, whereas, models G to I incorporate a Trombé wall directly in front of the external wall. The Trombé wall is used in addition to the kitchen conservatory to pre-warm external air for the first floor rooms in models G to I (see Figure 1.6). All the models include 100 mm of externally placed insulation. Considering that the esh units are built into a sloping hillside at 1:10, the earth cover on the ground floor is exactly the same for all models, except model S (see Figure 1.7 below). Thus, the variations to the earth cover are to the first floor walls and on the roof.

Unfortunately, it was not possible in Tas Lite to successfully simulate models G to I with their first floor walls separated into Trombé wall segments and non Trombé wall segments. Therefore, rather than provide a non-insulated buffer wall as part of the Trombé walls, as recommended by Kachadorian (1997) and the IEA (1997), it was decided that the wall would remain insulated as in models A to C. The only difference is the inclusion of a darkened surface on the outside face of the buffer wall, in order to increase its absorption of infra-red radiation.

**Table 1.1: Computer Models of the Author's Earth Sheltered Houses**

| Model | Earth (mm) | Insulation (mm) | 1st floor design configuration |
|---|---|---|---|
| A * | 1500 | 100 | Insulated & exposed external wall |
| B | 750 | 100 | Insulated & exposed external wall |
| C | 250 | 100 | Insulated & exposed external wall |
| G | 1500 | 100 | Insulated buffer wall & part insulated Trombé glazing |
| H | 750 | 100 | Insulated buffer wall & part insulated Trombé glazing |
| I | 250 | 100 | Insulated buffer wall & part insulated Trombé glazing |
| S | NIL | 100 | Insulated & exposed external wall |

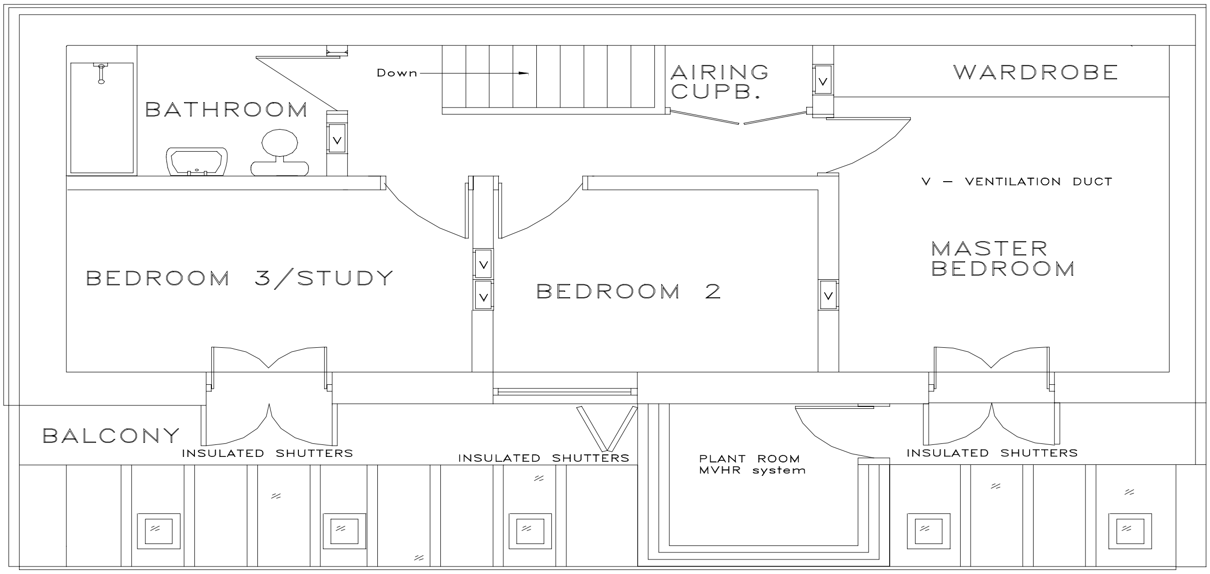


Figure 1.2: First Floor Plan For One Of The Pair Of Semi-Detached Two-Storey Earth Sheltered Houses, Without Trombé Walls

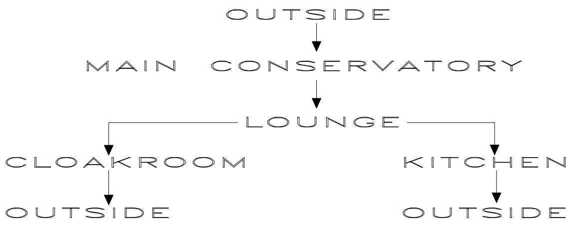


Figure 1.3: Ventilation Routes In The Ground Floor Rooms For Tas Lite Models A To C And S

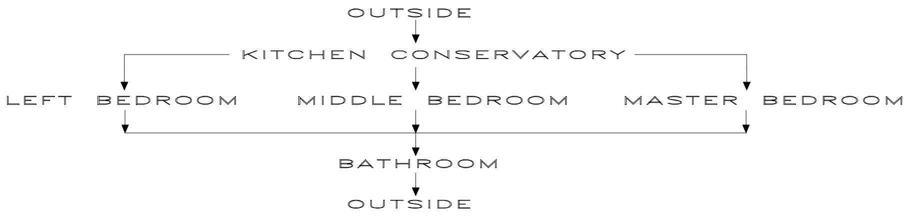


Figure 1.4: Ventilation Routes In The First Floor Rooms For Tas Lite Models A To C And S

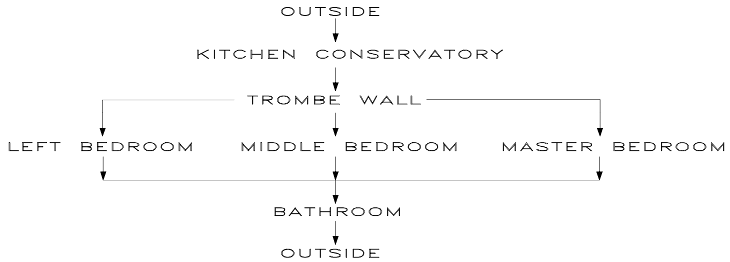


**Figure 1.5: Ventilation Routes In The First Floor Rooms For Tas Lite Models G To L**

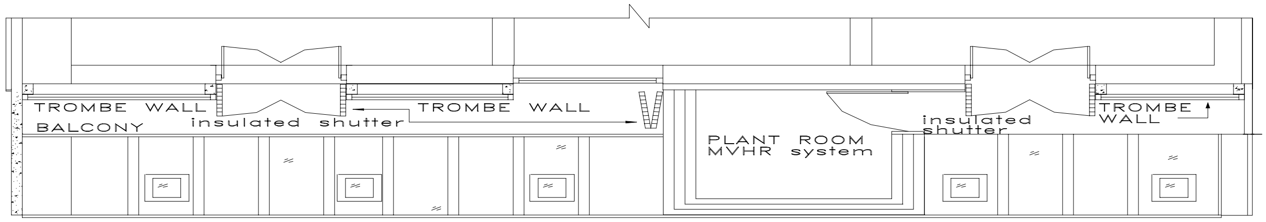


**Figure 1.6: First Floor Plan, External Wall Option 2 For Models G To I**

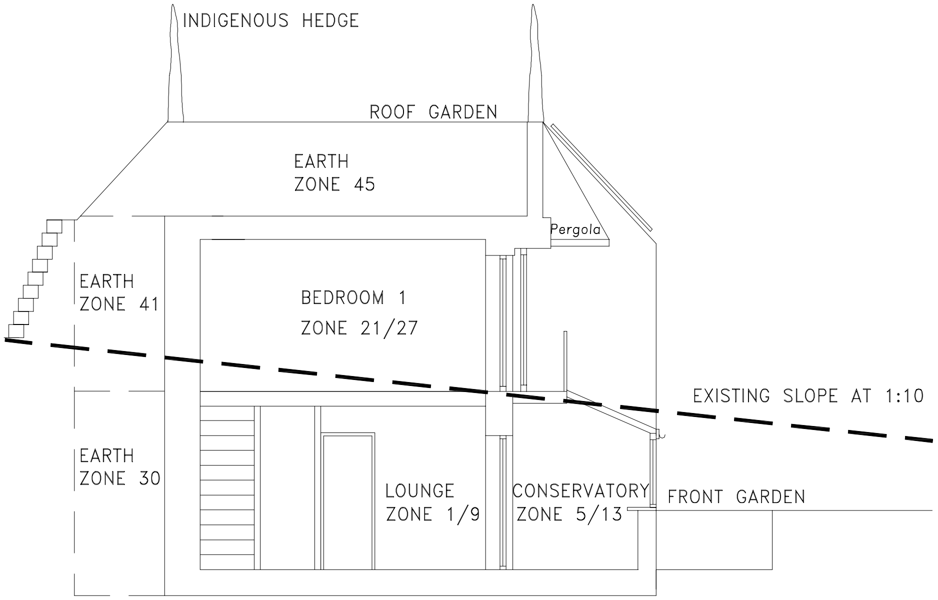


**Figure 1.7: Side Section Of Models A-C & G-I Illustrating The Position Of The Earth Zones**

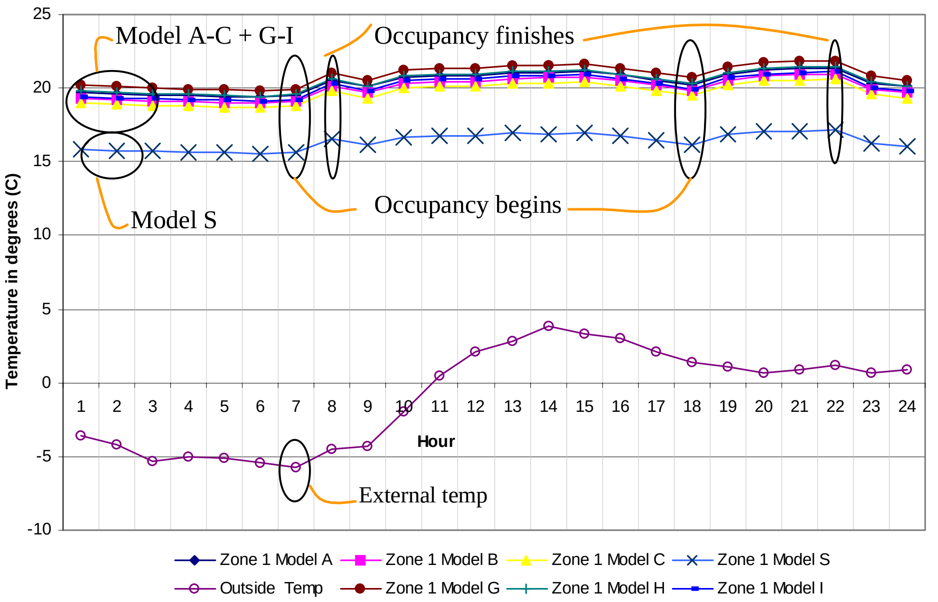
## 1.2 Results

The computer simulation results are presented for the coldest day in the winter of the climatic data year 1985. The external temperature on this test day meets CIBSE's (1986) recommended extreme external design temperature for South Wales (day 79 = -5.7 $^{o}$C at 7.00). CIBSE's (1986) recommended design temperatures for internal habitable rooms, Borer's (1998), Pearson's (1994) and Smith's (1991) comfort ranges are used as benchmarks for measuring the thermal performance of the internal habitable rooms.

***Ground floor lounge***

The simulation results presented demonstrate that very stable internal resultant temperatures are maintained compared with fluctuating external air temperatures in all models. It is shown that as external temperatures fall rapidly during the night (Graphs 1.1 to 1.2) the internal temperatures in the lounge and master bedroom, show very few signs of moving from their steady state trend. This trend is common to models A, B and C with their three variations in earth cover and model S with no earth cover. However, the temperature profile in model S is much lower than the temperature profiles in models A, B and C on day 79, which clearly demonstrates the benefit of earth sheltering combined with passive solar design techniques during winter days. The almost identical temperature profiles in the lounge (zone 1 - Graph 1.1) of models A, B and C demonstrate the thermal benefits of building the esh units into the ground where the earth cover remains the same to the rear and side external walls. In the lounge, model A records the highest internal resultant temperatures, whereas, model B records internal resultant temperatures on average 0.4 degrees Kelvin (K, hereafter) and model C records temperatures on average 0.7 K lower than model A. These small differences in temperature are very interesting considering that both model B (750 mm) and model C (250 mm) have much less earth cover sheltering their first floor walls and roof compared to model A (1500 mm).

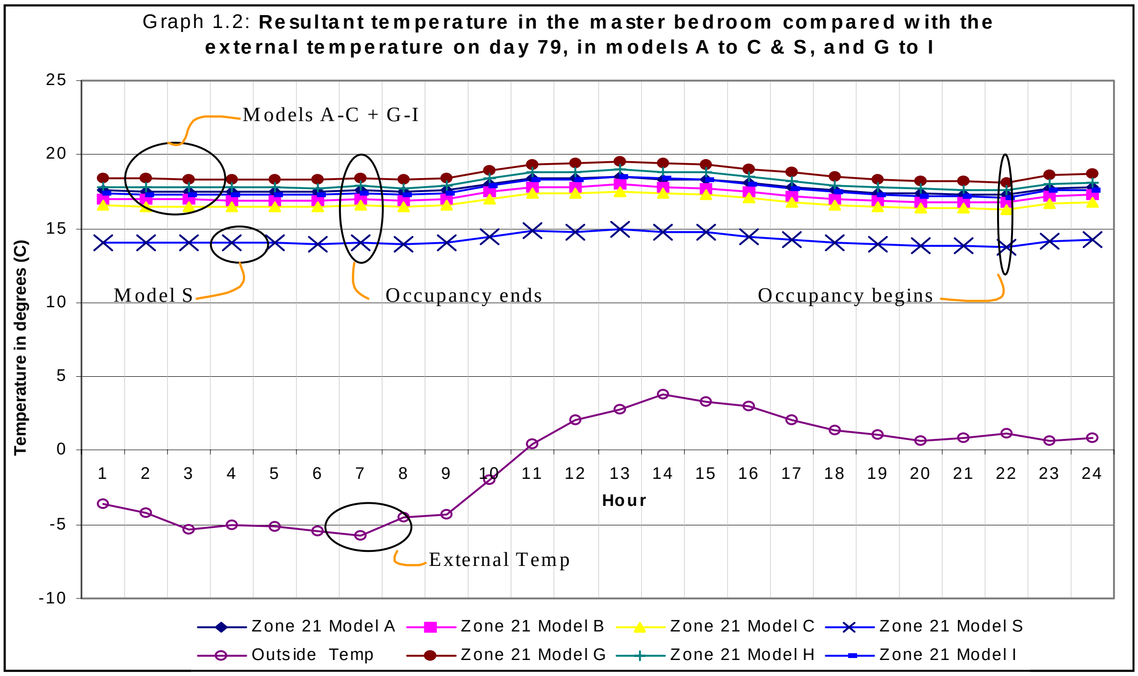
Graph 1.1: **Resultant temperatures in the lounge compared with the external temperatures on day 79 in models A to C & S, and G to I**



In the lounge the internal resultant temperatures throughout the day and evening in models A, B and C fall well within the recommended comfort range of 18.0 to 23.0 $^{o}$C (Borer 1998, Pearson 1994, and Smith 1981). However, on day 79 only zone 1 in model A can reach CIBSE's (1986) recommended design temperature for living rooms of 21.0 $^{o}$C. This occurs only at around 21.00, when the living room has been occupied for three hours.

The stable nature of the internal resultant temperature in contrast to the external temperature in both the ground floor and first floor rooms of the esh units (regardless of the depth of earth cover) and model S means that once heat gains from appliances, solar gain and occupancy are withdrawn the internal resultant temperatures do not fall rapidly. The internal temperatures decline gradually and return to their steady state temperature profile for the day, as illustrated in Graph 1.1 below. However, what is particularly interesting is that model S with no earth cover records internal resultant temperatures 3.0 K to 4.0 K lower than those recorded in models A, B and C (also see Table 1.2).

In Graph 1.1, it can be seen that when the lounge is unoccupied overnight, when the only heat gains are from pre-warmed air from the conservatory, the internal temperatures drop very slowly losing 0.5 K in zone 1 in models A, B, C and S. This is over a time when the external temperature drops by 3.7 K. In models A, B, C and S on day 79, at 7.00 single adult occupancy (zone 1) raises the temperature by approximately 1.0 K over one hour. When the esh unit is unoccupied between 8.00 and 18.00 and the only heat gains are from pre-warmed air and direct solar gain, the temperature drops by only 0.3 K in zone 1.



Graph 1.2: **Resultant temperature in the master bedroom compared with the external temperature on day 79, in models A to C & S, and G to I**

**Table 1.2: Summary of the lounge temperature ranges in models A, B, C & S on day 79**

| Model & Zone | Resultant Temperatures ($^oC$) at specific times on day 79 | | | | |
|---|---|---|---|---|---|
| | 7.00 * | 8.00 ** | 18.00 * | 19.00 ** | 21.00 *** |
| A. 1 | 19.5 | 20.6 | 20.2 | 20.9 | 21.3 |
| B. 1 | 19.1 | 20.2 | 19.8 | 20.5 | 20.9 |
| C. 1 | 18.8 | 19.8 | 19.5 | 20.2 | 20.6 |
| S. 1 | 15.7 | 16.6 | 16.2 | 16.8 | 17.1 |
| Range i (a1-b1) | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 |
| Range ii (a1-c1) | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Range iii (a1-S1) | 3.8 | 4.0 | 4.0 | 4.1 | 4.2 |

* occupancy commences; ** 1 hour occupancy; *** 3 hours occupancy

It was assumed that in the left esh unit the single adult would return to the house at 18.00. Consequently, at 18.00 the internal temperatures start to increase once again as the occupant returns from work, but stabilise at 20.00 and remain constant in all models until 22.00 when the occupant goes to bed. This rise in the temperature and maintenance of a steady temperature for two hours whilst the external temperature is continually dropping from 3.0 $^oC$ to -0.5 $^oC$, is particularly important when there is no form of active space heating in the esh unit. Although, model S behaves in a similar manner to models A, B and C, it is significant that the temperatures in model S are between 3.0 K to 4.0 K lower than in models A, B and C. At 22.00 when the occupant leaves the lounge zone 1 loses 1.0 K until 23.00.

Table 1.2, shows five key times during day 79 when the lounge has been occupied for a period of time or the occupation period has just commenced. It can be seen that zones 1 in models A, B and C remain within the recommended comfort range of 18.0 to 23.0 $^oC$ (Borer 1998, Pearson 1994, and Smith 1981) at all hours during day 79. However, model S records internal resultant temperatures which are well below 18.0 $^oC$ and that are between 3.5 K and 4.2 K lower than the internal resultant temperatures recorded in model A on days 79. This demonstrates that one of the many thermal benefits of earth sheltering is that it reduces heat losses from internal rooms when the external temperatures become lower, making internal resultant temperatures slightly more stable even in the short term. Table 1.3 illustrates how on day 79 the internal resultant temperatures recorded in zone 1 of models G to I are between 0.5 K (2.5%) and 0.8 K (4.5%) higher than the same rooms in models A, B and C. This is without any additional heat gains on the ground floor compared with the design of models A, B, C and S. These higher temperatures are a direct result of the first floor buffer wall and Trombé glazing which reduces heat losses through the buffer wall and increases heat gains to the first floor rooms.

**Table 1.3: Summary of the lounge temperature ranges in models G, H & I on day 79**

| **Model & Zone** | **Resultant Temperatures ($^o$C) at specific times on day 79** | | | | |
|---|---|---|---|---|---|
| | 7.00 * | 8.00 ** | 18.00 * | 19.00 ** | 21.00 *** |
| G. 1 | 20.0 | 21.0 | 20.7 | 21.4 | 21.8 |
| H. 1 | 19.6 | 20.6 | 20.3 | 21.0 | 21.4 |
| I. 1 | 19.2 | 20.3 | 19.9 | 20.7 | 21.0 |
| Range I (g1-h1) | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Range ii (g1-i1) | 0.7 | 0.8 | 0.7 | 0.8 | 0.8 |

* occupancy commences; ** 1 hour occupancy; *** 3 hours occupancy

***First floor***

The temperature range between models A and B and between models B and C is greater in the first floor rooms than in the ground floor rooms (compare Graph 1.2 with Graphs 1.1). As with the ground floor rooms, model A with the thickest earth cover of 1500 mm records the highest temperatures in the first floor rooms relative to models B, C and S. In addition, the difference in temperature between model A and model S is also much higher in the first floor rooms than in the ground floor rooms. However, in the master bedroom the recorded internal resultant temperatures are on average 3.1 K lower than zone 1. Furthermore, the internal resultant temperatures in models A to C and S are all below 18.0 $^o$C, which is CIBSE's (1986) recommended design temperature for a bedroom, and the lowest comfort temperature (Borer 1998, Pearson 1994, and Smith 1981). It is apparent, when comparing the results in Table 1.4 with the results in Table 1.5 that the additional pre-warming of the ventilation air through the Trombé wall leads to higher internal resultant temperatures in models G to I than in models A to C. Zone 21 in model G, records internal resultant temperatures that exceed 18.0 $^o$C, at all times during day 79. However, model H with 750 mm of earth cover is only able to exceed 18.0 $^o$C after the first hour of occupancy at 23.00. Model I, with only 250 mm of earth records very similar temperatures to model A, which are below 18 $^o$C at all times.

**Table 1.4: Summary of the master bedroom temperature ranges in models A, B, C & S on day 79**

| **Model & Zone** | **Resultant Temperatures ($^o$C) at specific times on day 79** | | |
|---|---|---|---|
| | 7.00 * | 22.00 ** | 23.00 *** |
| A. 21. | 17.6 | 17.3 | 17.7 |
| B. 21 | 17.0 | 16.7 | 17.2 |
| C. 21 | 16.6 | 16.3 | 16.7 |
| S. 21 | 14.1 | 13.8 | 14.2 |
| Range i (a21-b21) | 0.6 | 0.6 | 0.6 |
| Range ii (a21-c21) | 1.0 | 1.0 | 1.0 |
| Range iii (a21-S21) | 3.5 | 3.5 | 3.6 |

* occupancy ends; ** occupancy commences; *** 1 hours occupancy

**Table 1.5: Summary of the master bedroom temperature ranges in models G, H & I on day 79**

| **Model & Zone** | **Resultant Temperatures ($^o$C) at specific times on day 79** | | |
|---|---|---|---|
| | 7.00 * | 22.00 ** | 23.00 *** |
| G. 21. | 18.4 | 18.1 | 18.6 |
| H. 21 | 17.9 | 17.6 | 18.0 |
| I. 21 | 17.4 | 17.1 | 17.6 |
| Range i (g1-h1) | 0.6 | 0.6 | 0.6 |
| Range ii (g1-i1) | 1.0 | 1.0 | 1.0 |

## 2. CONCLUSIONS

On day 79 which meets CIBSE (1986) recommendations for the coldest winter day in South Wales it has been demonstrated that models A, B and C with three variations in earth cover clearly record considerably higher and more comfortable internal resultant temperatures than model S, which has no earth sheltering to any of it's structure. It has been shown that in all models the highest internal resultant temperatures are recorded in the ground floor rooms where the volume of earth behind, underneath and to the side walls of the esh unit's structure is the greatest. Furthermore, in the temperature range between models for the ground floor is very small, which is due to the fact that the earth sheltering the structure is exactly the same for all models on the ground floor.

In addition, it is apparent that occupancy from one adult makes little difference to the internal resultant temperatures in the ground floor rooms. However, in the first floor rooms occupancy from one adult does contribute significantly to higher internal resultant temperatures. All models show that their first floor rooms record lower internal resultant temperatures than in their ground floor rooms. Furthermore, only model G with the greatest earth cover (1500 mm) and a Trombé wall which provides additional pre-warming of the ventilation air to the first floor rooms, as able to record temperatures that exceed the recommended temperature for a bedroom of 18 $^{o}$C.

It has been shown that in the internal resultant temperatures can vary by as much as 1.0 K between the model with the greatest earth cover and the model with thinnest earth cover. Model A and G with the thickest earth (1500 mm) sheltering the first floor walls and covering the roof records the highest resultant temperatures in all rooms and at all times on day 79.

From the two design options it is has been shown that the inclusion of a passive solar conservatory on the ground floor and Trombé wall on the frist floor leads to the highest internal resultant temperatures. It has been suggested that, if the limitations in the Trombé wall design could be overcome, this could be included on the ground floor, rather than a passive solar conservatory.

The authors of this paper are currently involved in a live earth sheltered dwelling and office project where monitoring is taking place to test the findings of the simulations reported here. The monitoring methodology for this latter project is discussed and is presented in a second paper at the conference: 'The monitoring strategy to test the energy performance of an UK designed earth sheltered family dwelling'.

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