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THE MONITORING STRATEGY TO TEST THE ENERGY PERFORMANCE OF A UK DESIGNED EARTH SHELTERED FAMILY DWELLING

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ABSTRACT

This paper discusses how findings from a thermal simulation study of a two-storey earth sheltered house (esh unit) at the University of Glamorgan, UK, influenced in part, the design of a single-storey esh unit. The completion of the single-storey esh unit, which is being built in the Lincolnshire Fenlands, near the East Coast of the UK, is planned for completion in late Spring 2002. The paper evaluates how 55 thermocouples are being built into the structure, the surrounding earth and a number of the internal rooms, during the construction of this esh unit. These probes are being positioned to record the temperatures of the earth at specific depths around, under and on top of the esh unit. In addition, they will monitor the thermal performance of a number of design features incorporated into the esh unit and the internal comfort conditions. The thermal monitoring study is intended to last for at least three years and is part of an MPhil/PhD study programme at the University of Glamorgan, which is being undertaken by the designer/owner of the esh unit. It is hoped some of the results from the monitoring exercise will validate the results from a dynamic simulation study of the same earth sheltered house.

KEYWORDS

Earth Sheltered House, Thermal Monitoring, Passive Solar Design, Low Embodied Energy

1. INTRODUCTION

A recent simulation study at the University of Glamorgan has demonstrated that there are three optimum design solutions for a two-storey, semi-detached earth sheltered house (esh unit), with family (two adults and two children) occupancy (Littlewood 2001i, 2001ii). The internal rooms in the three optimum design solutions record resultant temperatures within the comfort range of 18 to 23 ^{o}C (Borer 1998, Pearson 1994, and Smith 1981). Each design solution provides a recommended configuration for the depth of earth cover to shelter the roof and first floor walls, the thickness and placement of insulation and passive solar collector to the first floor rooms. A single-storey esh unit is currently being built in the Lincolnshire Fenlands, which follows the recommended configurations from one of Littlewood's (2001i, 20011ii) optimum design solutions above, and is due to be completed in early Spring 2002.

Figure 1 shows the progress of the single storey esh unit as of November 2001. To test whether the recommended design configurations work in practice, as they have done in a computer simulation, 55 thermocouples will be installed into the earth, the structural interfaces and a number of internal rooms of the Lincolnshire esh unit.

Figure 1: Single-storey, UK built, esh unit as of November 2001

1.1 Earth Sheltered House Design

Figure 2 below illustrates the floor plan of the single-storey esh unit, currently being built in the Lincolnshire Fenlands, for a family of two adults and three children. The geographical relief of the Lincolnshire Fenlands (LFs) is almost completely flat. Consequently it was not possible to obtain planning permission for a two-storey esh unit, and Harrall the designer of the above esh unit, opted for a single-storey esh unit. Furthermore, developing a two-storey esh unit in the LFs would negate one of the benefits of earth sheltered houses (esh units), and that is their low visual impact. For more details on the low visual impact benefit of esh units refer to Littlewood (1998), Carmody (1981) and Baggs (1991). The LFs are situated at or below sea level, and therefore, during periods of heavy rain, particularly between October and April each year, many of these areas are prone to flooding, where the water table sits at ground level. In addition, it has been suggested that many parts of the LFs will be permanently flooded in the next 20 to 50 years due to rising sea levels, which is as a direct result of global warming. Consequently, the finished floor level in Harrall's esh unit will be at least 750 mm (0.75 m) above the level of the existing ground, which can be seen on Figure 1 above.

The floor plan of Harrall's esh unit contains 150 m^2 of living space, with all the internal rooms facing within 30 degrees of south. The esh unit has been designed around a number of passive solar design features, as summarised in Table 1 Kachadorian (1997), IEA (1997), DTI (1994), Winter (1998). In addition, Harrall's esh unit will also test a selection of Littlewood's (2001i, 2001ii) recommendations for earth cover, insulation specification internal layout, and passive solar collector, summarised in Table 2.

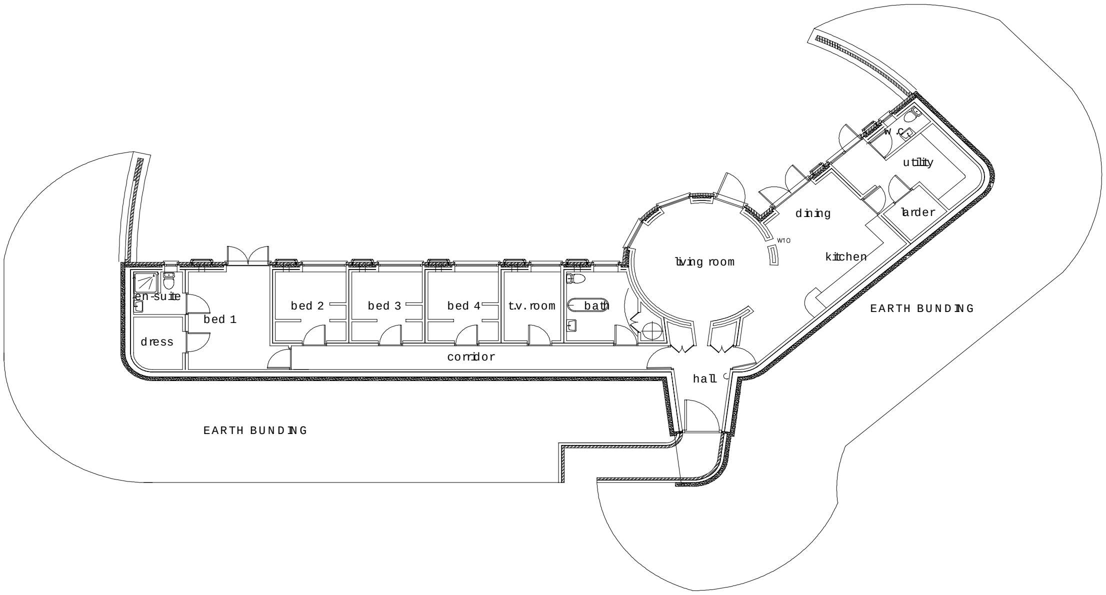

Figure 2: Floor plan of Harrall's © single-storey Lincolnshire esh unit

Table 1: Passive Solar Design principles

Orientating exposed high performance (1.5 W/m^{2o}C) windows due South or within 30 degrees of South (Northern latitudes)
Appropriately positioned super-insulation (0.2 to 0.13 W/m^2 ^{o}C)
Ventilation heat-recovery systems or passive ventilation
Passive solar collector
Massive structure for thermal storage

Although, the windows in Harrall's esh unit will face within 30 degrees of south they cannot be classed as high performance windows, as they are only double glazed timber units and do not include a gas fill in the glazing cavity. The reason for Harrall not opting for high performance windows is that his design philosophy for his esh unit is one of providing a low cost, low tech, low maintenance, but high quality and sustainable design solution for single-storey housing, which should be attractive to social housing providers. In fact as this paper was going to press a social housing provider in South Wales, UK showed interest in a scheme formulated by Littlewood, for a number of esh units, to be built on at least one site. These schemes will probably be the first UK development with esh units, for the social housing sector.

Table 2: **Littlewood's recommendations for ESH (2001)**

250 mm of earth cover
Trombé wall as a passive solar collector
300 mm of externally placed expanded polystyrene insulation
Elevational plan

The insulation actually used will consist of 150 mm of externally placed extruded polystyrene, with a U value of 0.15 W/m^2 ^{o}C, which is equivalent to that recommended in Table 2 above. The ventilation will be completely passive with the inclusion of trickle ventilation to all windows. To induce natural cooling into the esh unit during the warm months of the year, the front door of the house, which is on the Northern elevation, can be left open. Similar to the doors and windows in buildings built around the Mediterranean, Harrall's front door is in two parts. The inner part of the door is solid, whereas the outer part of the door is similar to an iron gate. This outer part of the door can be locked for security, whilst the inner part of the door can be left open so that warm air can escape and fresh air can circulate through the dwelling.

Unlike other UK esh units, which include a passive sunspace or corridor in the place of an active space heating system, Harrall's dwelling will not incorporate a passive sunspace. Instead, following Littlewood's (2001i, 2001ii) and Terman's (1985) recommendations Harrall's esh unit will incorporate a series of eight Trombé walls, in the external south facing façade see Figure 3 below. The living room will be the only internal room, which is positioned behind the south facing external wall not to incorporate a Trombé wall. The south facing face of each Trombé wall provides 1.2 m^2 of glazing, and therefore the total area of glazing in the Trombé walls will be 9.6 m^2. As recommended by Kachadorian (1997) and Terman (1985) the buffer wall (which is the wall behind the Trombé glazing) includes 'hit and miss' ventilation grills. However, Baker (1985) suggests that there are a number of disadvantages in the inclusion of 'hit and miss vents' in a Trombé wall. In that they do not allow any control over the manner in which heat energy enters into internal rooms behind the buffer wall (by conduction or radiation), other than by manually closing and opening the vents (Baker 1985). In addition, even when these vents are closed during winter evenings it is difficult to prevent unwanted heat losses to the external climate (Baker 1985). Furthermore, one of the key design strategies for super-insulating a building is that the fabric and structure must be super tight (IEA 1997). Thus, the inclusion of vents in the buffer wall is a clear infringement of this strategy (Baker 1985).

Finally, the main material for the construction of Harrall's esh units is reinforced concrete (floor, external walls and roof) and dense concrete blocks (internal floors). The concrete floor will be power-floated and left uncovered as an integral part of the dwelling. One of the main criticisms of developing esh units is that of the vast quantities of concrete used in their construction. This is because concrete has a relatively high embodied energy, and its production leads to excessive carbon dioxide emissions (CO_2), due to its cement content. For example for every tonne of cement, which is produced, one tonne of CO_2 is emitted into the atmosphere. To reduce the embodied energy and the CO_2 emissions from the concrete used in Harrall's esh unit the concrete will be produced locally, with recycled aggregate and brick dust as a partial cement replacement. The Building Materials Research Unit has developed this concrete at the University of Glamorgan, and it will be first time it is used in a commercial application.

From Littlewood's (2001i, 2001ii) computer simulation of a two-storey esh unit for a family (two adults and two children) it was found that 250 mm of earth cover sheltering the first floor walls and roof was the optimum depth of earth cover, in combination with a Trombé wall and 300 mm of expanded polystyrene. The criteria for an optimum design solution was that the internal rooms within the two-storey esh unit recorded resultant temperatures between 20 and 23 ^oC, without any form of active space heating. Harrall is opting to use 750 mm earth cover because Baggs (1991) recommends this depth of earth cover for planting and sustaining shrubs and small trees.

To test whether the above passive solar design features in combination with the earth sheltering optimum design features enable the internal rooms within Harralls' esh unit to record temperatures within the comfort range of 18 to 23 ^oC, a monitoring program is planed for at least two years on the completion of the dwelling.

1.2 Monitoring Program

Figure 3 and 4 illustrate the positioning of a number of thermocouples in the structural interfaces and on the floor plan of Harrall's esh unit. In March 2001 a stand-alone weather station was installed on the development site of Harrall's esh unit, with six earth probes at 250 mm intervals below the base of the station (see Figure 5). The weather station is recording the air temperature, the wind direction and speed, humidity, direct, diffuse and total radiation, and precipitation. In addition, at various stages in the development process of the esh unit, 55 thermocouples are being installed into the earth, sheltering the walls, roof and floor; a number of the structural interfaces and a number of the internal rooms, as highlighted above in Figure 3 and below in Figure 4. The thermocouples are to monitor surface and air temperatures in the esh unit.

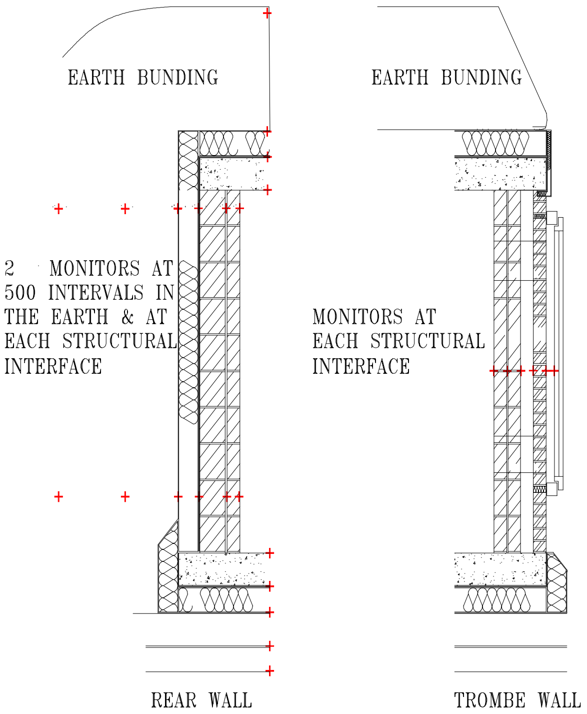

Figure 3: Thermocouple Positions in Each Trombé Wall and the Rear External Wall

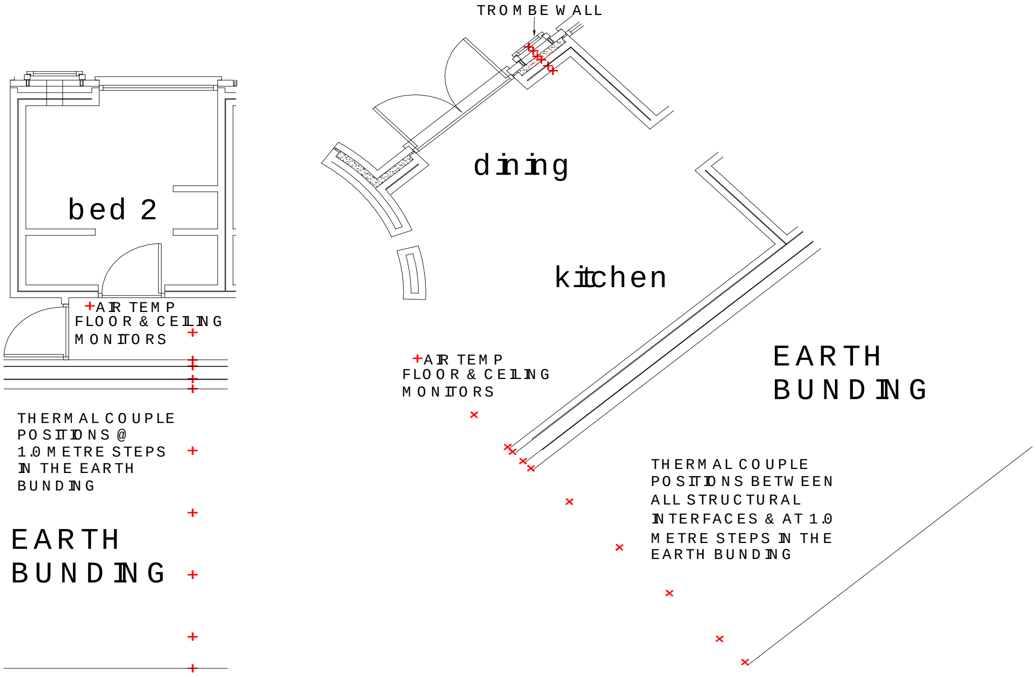

Figure 4: Thermocouple Positions In The Floor Plan

Figure 5: Weather Station Positioned on Site

2. CONCLUSIONS

This paper has discussed briefly the design rational for a single-storey esh unit in the LFs for a family of two adults and three children. The esh unit has been designed around passive solar design principles, and optimum earth sheltered design features, identified in a recently completed PhD study, at the University of Glamorgan, UK. From a thermal simulation exercise of a two-storey esh unit, the PhD study recommended the use of a series of Trombé walls as passive solar collectors, 750 mm of earth sheltering to the roof and first floor walls, and the equivalent of 300 mm of externally positioned expanded polystyrene. The paper concludes by discussing a thermal monitoring program, which commenced in Spring 2001, to test the thermal performance of the esh unit by recording hourly temperature readings from 55 temperature probes. The monitored results will be compared with climatic data and with the earlier simulation work conducted by the University of Glamorgan. It is intended that a snap-shot of monitored results, climatic data and video footage of the construction process and peoples attitudes of the project who have the site, will be included on an interactive web site which is currently being built at the University of Glamorgan. The web site and a series of technical videos will allow dissemination of the results to a wider audience than the UK. A number of social housing providers in the UK have shown keen interest in the research to date, with a view to developing a community of earth sheltered houses.

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