PROS AND CONS OF USING STRUCTURALLY INSULATED PANELS IN SRI LANKA

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Abstract: Structurally Insulated Panels (SIPs) are extensively used in energy efficient buildings all over the world. SIPs can be simply introduced as a building material consisting of an insulating layer in between two structural wythes. Since SIP technology is fairly new to Sri Lanka, only few studies have been carried out to check thesuitability of SIP technology in Sri Lanka. SIPs can be used as walling materials, roofing materials and for slab construction instead of conventional building materials such as burnt clay bricks, cement sand blocks or conventional reinforced concrete slabs. This paper describes an experiment carried out to determine the thermal performance of SIP wall, Cement block wall and Burnt clay brick wall model houses. Further,this presents the results obtained from a computer simulation regarding the cooling loads required for above mentioned models. A cost comparison has been done to evaluate the costs of various wall construction techniques used in Sri Lanka. As a whole, this paper describes pros and cons of using SIPs in Sri Lanka.

Keywords: Structurally Insulated Panels , Constructability, Thermal Performance, Insulation

1. Introduction

The rapid growth of construction industry and modern technological advancement inthe worldtoday have led the construction industry to go beyond its boundaries. According to De Albuquerque, El Debs, & Melo (2012), today construction industry is in search for more innovations and ways to increase the efficiency of construction while minimizing the waste. As a solution to overcome these issues, number of new construction materials have come to be used. Structurally Insulated Panels are one such material which have been commercially used in America and developed countries since 1960s.However,the first invention of SIP technology was done by Forest Products Laboratory (FPL), established by the U.S. Department of Agriculture, in 1935 in Madison, Wisconsin (Morley, 2000). Although SIPs are not popular among Sri Lankans due to lack of knowledge and information about them, they have been used in severalprojects in Sri Lanka withinthe last two decades (Brandix Office Complex-Ratmalana, Wadulla Wattha Housing Project, Hemas Southern Hospital). SIPs can be simply introduced as a building material consisting of an insulating layer in between two structural wythes.

2. Objectives and Methodology

The main objective of this research is to identify pros and cons of using SIPs in Sri Lankan context. A comparison on thermal performance, cooling loads, duration of construction and cost of construction among SIP walls, Cement block wall and Burnt clay brick wall has been carried out in this research. Following methodology was adopted in the research.

- Field surveys were done to identify durations of construction involved in house constructions using SIPs, Cement block and Clay bricks.
- Building Schedule of Rates (BSR) of reputed companies valid for year 2013 were analyzed to retrieve information on construction cost for each walling material (SIP wall, Clay Brick wall, Cement sand block wall, CSEB block wall).
- A model house was constructed using SIPs as walling material. Calicut tiles were

used as roofing material. Previously constructed two model houses of same scale, made of burnt clay brick wall and cement block wall were thatched with Calicut tiles.

- Three model houses were tested for indoor temperature variation using thermocouples and a digital data logger. Data logging was done every 5 minutes for 4 days.

- Computer simulations were done for the three models using Derob-LTH to determine indoor thermal performance.

- Cooling load for each model was evaluated using the DEROB compuer simulation.

3. Literature Review

3.1 What are SIPs

SIP technology is gaining popularity since they can be used as walling materials, roofing materials and for slab construction instead of conventional building materials such as burnt clay bricks, cement sand blocks or conventional reinforced concrete slabs.Common facing materials (wythes) are cement mortar, concrete, sheet metal or plywood. PCI Committee (Seeber, Andrews, Baty, & Cambell, 1997) recommends a minimum 51 mm layer thickness of insulation.The common insulation materials are Expanded Polystyrene Foam (EPS), Extruded Polyurethane Foam (XPS) and Polyurethane Foam (ASTM-D30 Committee, 2007).Normal tor steel, mild steel or shop fabricated wire mesh are used to produce precast concrete or cement mortar layered insulated panels.Steelconnectors are used between two concrete layers through the insulation to enhance the composite action of SIPs.Figure 1 shows atypical section of a SIP.

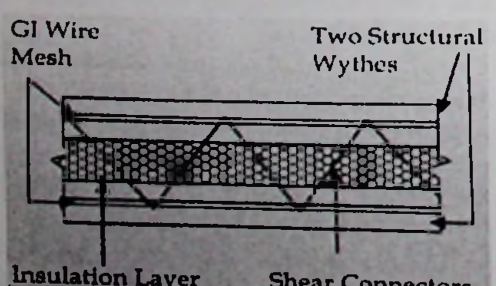

Figure 1: Typical Section of a Structurally Insulated Panel

3.2 Thermal performance

Thermal comfort is defined in British Standard BS EN ISO 7730 (2005) as "the condition of mind, which expresses satisfaction with the thermal environment". So the term "thermal comfort" describes a person's psychological state of mind and is usually referred in terms of whether someone is feeling too hot or too cold. Heat can enter the building through windows or it can heat the building shell to a higher temperature than the ambient, increasing the heat transfer through building envelope. Solar gain can be reduced by providing adequate shading from the sun, light coloured roofing materials, heat reflective paints, coatings and various types of insulation for building envelope. Raised indoor temperature will cause thermal discomfort to its occupants. Therefore thermal comfort is very important inside buildings (Jayasinghe&Priyanwada, 2002).

Thermal performance of a panel can be evaluated by estimating its thermal resistance (R-value). The R-value of a material or assembly of materials is a quantity that is often used to describe the thermal performance of building construction. R-value calculation for a SIP includes analyzing the panel for the effects of thermal bridges (Holman, 1981). The placement of the connectors interrupts the continuous insulation layer. These interruptions are known as thermal bridges. Depending upon the material used to make the connectors in a panel; these thermal bridges can conduct energy at a much higher rate than the insulation, thus reducing the effectiveness of the insulation. According to McCall (1985), in some cases, the thermal performance of a panel can be decreased by as much as 40% due to the heat conducted through the shear connectors and the concrete regions that penetrate the insulation.

According to Lee & Pessiki (2006), concrete wythe thickness does not have a significant effect on the R-value of both two and three wythe panels. But insulation thickness does have a significant effect on the R- value .

According to Halwathura and Chamila (2012), DEROB can be used to simulate buildings in Sri Lankan context and this can be taken as a good tool for comparison by changing one parameter, while keeping others constant. Hence, DEROB can be used to compare the thermal performance of various walling materials.

3.3 Cost of construction

SIPs are mostly factory produced material while cement blocks and clay bricks are on-site constructions.Many researchers (Haas et al., 2000; Goodier & Gibb, 2006) identified overall cost for a project that uses off-site work can be less than a traditional on-site work if local labour for on-site work is very expensive or inefficient. However, Baba et al. (2012) argued factory-based products have been more expensive than traditional type of construction although preliminary costs are less due to reduced project duration and the low human resource requirement. Projects that use factory-based products have the ability of reducing the labour and costs, since majority of the construction work will be carried out within the factory at a set location (Baba, et al., 2012). Therefore, this reflects that the higher costs of off-site construction are incurred due to material costs. Table 1 is referred to potential cost savings and additions of factory-based products (Baba et al., 2012).

Table 1: Cost additions and Cost savings of factoty based products

Potential cost addition	Potential cost saving
Real costs of fabrication facility	Productivity cost savings from off-site fabrication
Additional costs from large capacity transportation	On-site savings due to shorter construction period
Additional costs from increased capacity of site craneage	On-site savings due to less on-site work and fewer workers

According toMullins & Arif (2006), the cost savings are in the same range for SIPs and conventional building materials. But time savings are much effective in using SIPs.In a controlled environment, where direct effect of sunlight and harsh weather cannot effect, the works are not delayed and quality becomes high (Baba et al., 2012). In addition, work is not interrupted and productivity can remain at a higher level.

The Sri Lankan Standarad 855-Part 1 (1989) has stipulated minimum axial load of 120 kN/m for single storey houses constructedusing cement hollow blocks. According to Rupasinghe, Baskaran, & Mallikarachchi(2012),the tested values for SIPs are also closer to that minimum range.

4. Field Investigation

A site investigation was carried out in order to identify the durations involved in various construction methods. These results are purely based on site investigations and data from the workers. These results may vary according the site conditions, skills of the workers and the technologies they are using.

SIPs are manufactured in 4ft x 8ft (1.22 m x2.44 m) panels with 50mm and 100mm foam core. Hence when one panel is erected it covers a total area of almost 3 m^2. Panels can either be fully factory fabricated with the mortar wythe or without the mortar wythe which is installed on-site. The dimension of commonly available burnt clay bricks is 215mm x 102.5mm x 65 mm. Cement sand blocks are of 100mm,150mm and 200mm thicknesses.

Three single storey houses which are constructed using SIPs, Clay bricks and Cement sand blocks were considered to evaluate the duration of wall construction and labour cost of construction. Labour costs were calculated for each house assuming a daily wage of Rs.1500.00 for a mason and Rs.900.00 for a labourer.

House-1: 755 ft^2 with SIP walls at Battaramulla (3 Masons and 6 Labourers)
House-2: 645 ft^2 with Cement blocks at Kuliyapitiya (2 Masons and 7 Labourers)
House-3: 710 ft^2 with Clay bricks at Kuliyapitiya (3 Masons and 5 Labourers)

Table 2 illustrates the duarations and labour costs involved with construction of walls for different walling materials.Only the construction of the exterior was only taken into the consideration.

Table 2: Duration of construction and total labour costs for different houses

House	1	2	3
Scaffolding(days)	1	1	1
Construction of walls (days)	6	9	10
Plastering (days)	7	6	7
Total (days)	**14**	**16**	**18**
Total labour costs in Rupees	**138,600**	**148,800**	**162,000**

5. Cost Analysis

A detailed cost analysis was carried out to compare the costs of different walling materials. This comparison is useful in comparing the effectiveness of different walling materials. These values were obtained by considering the Building Schedule of Rates of reputed companies in Sri Lanka for the year 2013.Table 3 illustrates the costs involved with different wall construction materials. These costs include both materials and labour costs.

Table 3: Cost of construction of various walling materials

Type of walling material	Cost for 1m² in Rupees
4"Thick SIP (Micro SIPs) (Area 10'x10')	3209.17 .
4" Cement Block wall in 1:5 cement:sand mortar	1167.46
Brick work in cement and sand 1:5 in 4.5" thick walls	1470.89
Brick work in cement and sand 1:5 in 9" thick walls	2532.36

6. Experimental Investigation

6.1 Scope

For the model house construction, 100 mm thick SIPs where insulation is 50 mm and wythe thickness of 25 mm each side produced by a manufacturer were used. A model house was constructed with SIPs parallel to the previously constructed models of cement block and clay bricks. Orientation of the three model houses were similar. Calicut tiles were used as the roofing material in the three models.These three models were tested using thermocouples for the temperature variation of inner and outer surface of walls.

6.2 Testing procedure

These models were created near the Civil Engineering Complex, University of Moratuwa.

- Four thermocouples were placed in each model house. Of them, two thermocouples were used in outer surface of two adjacent wall panels and the other two were placed in their respective inner surfaces. Two thermocouples were used to measure the atmospheric temperature.
- All the end nodes of thermocouples were connected to a data logger to measure the temperature at 5 minutes intervals. Data logging was done for four days continuously.Retrieved information for the 3 model houses were plotted on the same graph.

Figure 2 shows the dimensions of the model house and figure 3 shows a model house under construction. Following are the 3 models used for the experiment.

Model 1: 225 mm thick brick wall with both side plastered
Model 2: 100 mm Cement sand block wall without the plaster
Model 3: 100 mm thick SIP wall with 50 mm insulation and 25 mm thick plaster both sides

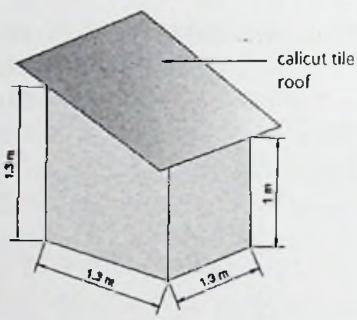

Figure 2: Dimensions of the test model

Figure 3: Partially constructed SIP model

6.3 Experimental results

Data retrieved from the data logger for each model were plotted on the same graph to observe the variations of indoor temperature when the walling material changes. Figure 4 shows the indoor temperature variation for different wall materials.

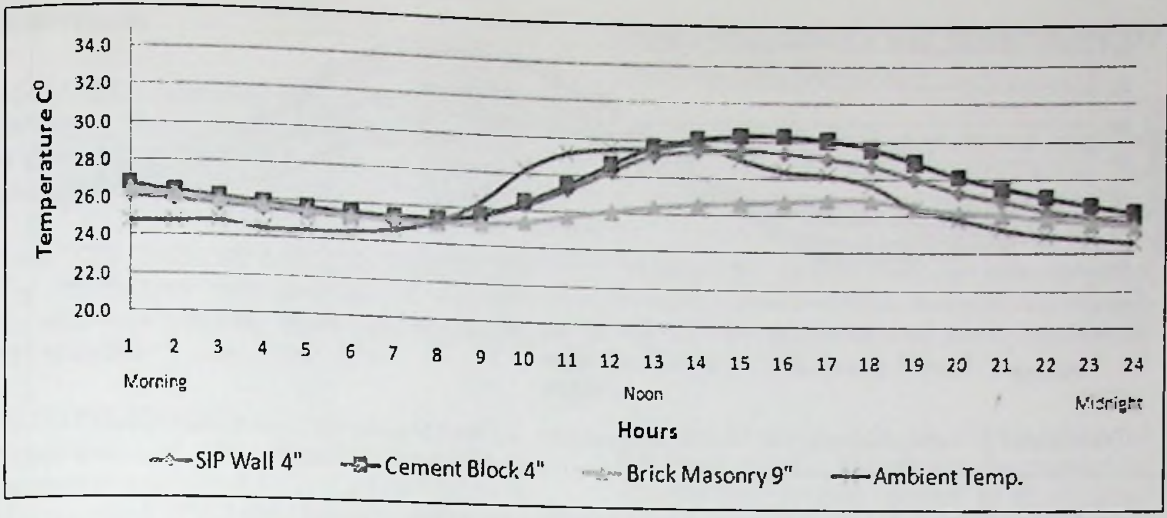

Figure 3: Indoor temperature variation for different walling materials

7. Computer Simulation

A computer simulation was done using the software DEROB-LTH(Dynamic Energy response of Buildings-LTH) to observe the theoretical behaviour of the model. It is a software which facilitates the creation of a 3D model of the buildings and analyze them with relevant geometrical climatic parameters. Simulation was done for the 3 model houses which were experimentally tested.

7.1 Data used in the computer model

The temperature variations retrieved from the experiment wereused as an input for the model. The material properties mentioned in the table 4 and 5 were also used as the input for the model.

Table 4: Material properties used in DEROB(Evans, 1980)

Material	Conductiviy (W/m.K)	Sp. Heat (Wh/kg.K)	Density (kg/m³)
Cement Plaster	1.2	0.28	2000
Brick wall	0.42	0.26	1400
Cement Block	1.1	0.23	2000
Calicut roof	0.95	0.35	1900
EPS Insulation	0.039	0.47	130
Earth	1.4	0.22	1300
Air	0.024	0.28	1.201
Concrete	1.7	0.24	2300

Table 5: Absorptance and Emmitance values (Evans, 1980)

Category	Colour	Absorptane %	Emmintance %
Cement Block	Light Grey	45	87
Plaster	Light Grey	45	87
Calicut Roof	Red-Brown	65	90

Following figure 5 shows the model created in DEROB to be used in the simulation.

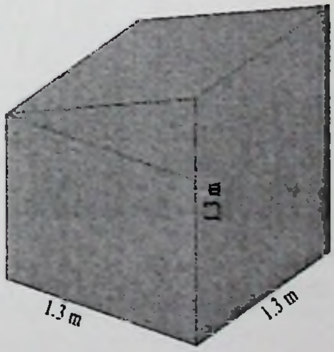

Figure 5: DEROB Model

7.2 Results: Indoor temperature variation

According to Halwathura and Chamila (2012) DEROB can be used to compare various walling materials. So here 4" SIP, 4" Cemnt block wall, 4.5" thick Brick masonry and 9" Brick was used to compare their thermal performance.

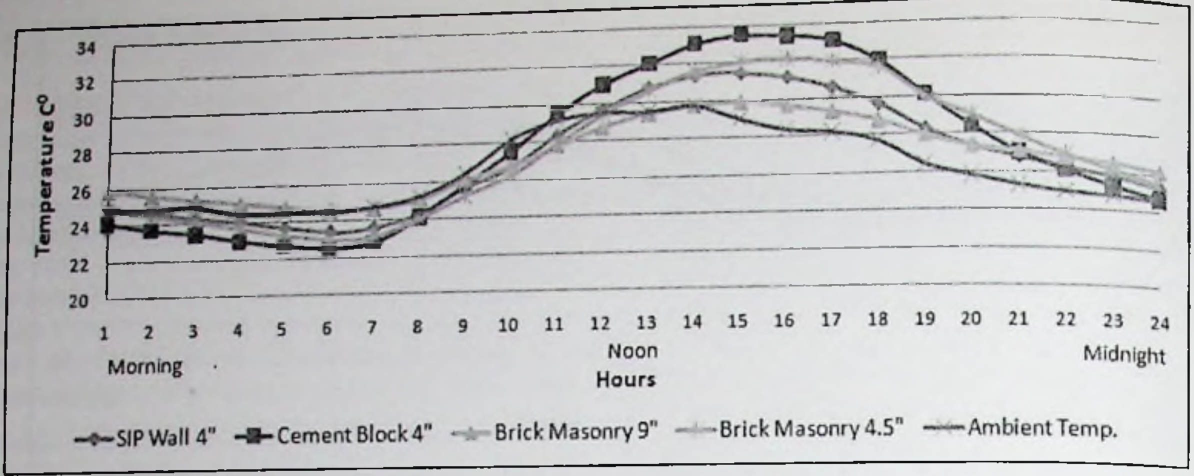

Figure 6: Indoor Temparature variations for various walling materials obtained from DEROB

7.3 Results: Cooling loads for models

DEROB software can be used to evaluate the cooling loads required to maintain a specific temperature inside the models during the considered time period.In this computer simulation, it is assumed that an indoor temperature of 26 ⁰C is maintained within a 24 hour duration and the average cooling load required for an hour was calculated. Table 6 shows the average cooling loads per hour for each model.

Table 6: Cooling loads for the models

Model	Cooling load per hour (Wh/h)
SIP wall model (4" thick)	21.1
Cement sand block wall model (4" thick)	55.6
Burnt clay brick wall model (4.5" thick)	41.2
Burnt clay brick wall model (9" thick)	23.3

8. Conclusions

According to the field investigation, it can be seen that by using SIP technology, the duration of construction can be reduced when compared to brick wall and cement block wall construction. Also labour cost involved in SIP wall construction is less compared to Cement block and Brick masonry.

When comparing the information gathered from BSRs regarding the cost of construction of various materials, it can be seen that the SIPs cost more than the brick walls and cement sand blocks . Cement sand blocks are the cheapest material available for house construction.

According to the experimental results obtained for the 3 models, it is proven that the model with the burnt clay bricks (9" thick) has the lowest indoor temperature. Cement block wall model shows a very high indoor temperature. SIP wall's performance is between the brick wall and cement block wall.

DEROB can be used to compare materials but it does not simulate the actual field situation.So DEROB computer simulation was used to compare the thermal performance of various walling materials. 4" SIP wall model shows the best thermal performance. 4" Cement block wall model has the lowest thermal performance. 4.5" Brick masonry wall model shows an intermediate thermal performance.

Cooling load required for the SIP model house has the lowest vaue. 4.5 " Brick wall model house requires a load as twice for SIP model. Cement block wall model requires the highest cooling load. SIPs perform well in the air conditioned environments.

Further research needs to be carried to check the thermal performance with different roofing materials anddifferent opening arrangements.Also a large number of houses should be monitored in order to evaluate the durations involved in construction process.

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