ENERGY USAGE AND THERMAL ANALYSIS OF A 400M² UPMARKET RESIDENCE SITUATED IN JOHANNESBURG, SOUTH AFRICA.

INTRODUCTION

The objective of this project was to analyse the performance of a residence with three Expanded Polystyrene (EPS) products/systems installed in comparison with a conventional unimproved design of the same residence.

The energy usage of the base-case building, with all applications typical of a residential building were developed using the VisuaIDOE® software. These were compared with the usage of the building with the three EPS products/systems improvement. The comparative costs of the base case and EPS products/systems were provided by industry and were used to develop Life Cycle Cost comparisons.

Internal temperature improvements resulting from the three EPS systems were demonstrated using the NewQuick® or Building Toolbox® software. This analysis also provided the 'percentage persons comfortable index' (PPC).

A comparison was drawn between the base case model (which was developed in detail), and the improved base case model which was modified with the three EPS products/systems. The base-case residential design and a description of the improved system are detailed in Annexure A.

The effective thermal performance of the 195mm EPS 'rib and block' suspended floor slab system (255mm overall slab depth) was calculated using the ASHRAE Zone Method. This method uses a series-parallel calculation around a conductive zone in order to account for transverse heat flows though insulation systems with highly conductive intrusions. Transverse heat flows do tend to be under-estimated by conventional calculation. A conventional simplified Fourier's Law method was applied for calculating the thermal transmittance of the 40mm thick EPS insulated cavity walling system. IS013370: Thermal Performance in buildings - heat transfer via the ground - calculation methods were applied for calculating the thermal transmission of the insulated slab (11JFS) on ground applications for input to the energy model below.

A VisuaIDOE® based computer modelling of the base-case, and three EPS systems, was performed. This built up the impacts of all building energy uses and accounts for their inter-relationship. For example, much of lighting energy ends up as heat and impacts on heating or cooling loads in buildings. The occupants of a building influence energy usage with their metabolic activity. Usage of appliances was also taken into consideration. The model was run for Johannesburg only.

The energy cost and capital cost impact of each system was developed. This data was used in a Life Cycle Cost (LCC) calculation. LCC method is accepted for energy cost evaluations as it provides a long term view which brings into account projected energy costs rather than short term costs. The energy cost escalation used in this report was 2.5% over the rate of inflation over 30 years. A discount rate of 7.0% was used. Predicted temperatures within the buildings and the PPC for the hottest hour, were obtained for comparison between the base-case and the improved system. These and the internal air & radiant temperatures were obtained via a NewQuick® model.

BASE – CASE MODEL DEVELOPMENT

Buildings of different occupancies have widely differing energy usage patterns and the influence of energy saving systems varies greatly for climatic regions. Building size, orientation, lay-out and material designs and equipment choices also influence energy usage.

In order to demonstrate the heating and cooling energy usage reductions resulting from the incorporation of the EPS improvements a 400m² modern flat roofed residential design with typically large window areas, based in a highveld climate region (using Johannesburg weather data), was proposed as the base case for the VisualDOE model.

It was assumed that heating was via under-floor electrical resistive heating and that cooling was via low efficiency split units.

Other energy appliance load intensity assumptions are detailed in the building description of Annexure A.

RESULTS

Thermal transmittance of systems

The Effective Thermal Transmittance of the EPS 'rib and block' suspended floor slab system (255mm overall slab depth) was calculated using the ASHRAE Zone method. A result of 0.48W/m^{2}K was reported. This result was six times the thermal resistance of the standard 255mm concrete slab which has a thermal transmittance of 3.2 W/m^{2}K.

The Thermal Transmittance of the EPS walling system with 40mm of expanded polystyrene within a double brick wall cavity was calculated using the simplified Fourier's Law. A result of 0.72 W/m^{2}K was achieved versus 2.63 W/m^{2}K for the un-insulated wall.

The Thermal Transmittance of the EPS flooring system with 40mm of expanded polystyrene (within a double brick wall cavity) was calculated using the simplified Fourier's Law. A result of 0.63 W/m^{2}K was achieved versus 2.04 W/m^{2}K for the un-insulated floor.

Energy Usage and heating and cooling load reduction

The VisualDOE model results are set out below:

The calculations included the base case unimproved building, the improved building with all proposed EPS systems incorporated and then three models which unload each of the three systems individually in order to assess the thermal efficiency of each product/system on its own. The final model in the series showed the performance of a building with IBR steel roof and plasterboard ceiling.

The sections of the VisualDOE report cover:

i. electrical usage by major application
ii. energy cost - impact on Life Cycle Cost
iii. energy usage by month (showing seasonality)
iv. monthly electrical power demand

Electrical Use Summary								
Alternative	**Lights**	**Equipment**	**Heating**	**Cooling**	**Fans**	**Hot Water**	**Ext. Lights**	**Total**
Electrical End-Use Totals (kWh)								
Modern or un-shaded Tuscan	22,349	7,450	17,107	7,680	13,745	14,804	394	83,529
Modern Tuscan EPS Roof, EPS floor & walls	22,349	7,450	4,036	9,059	12,883	14,804	394	70,975
Modern Tuscan EPS roof, EPS floor only	22,349	7,450	9,484	7,579	13,140	14,804	394	75,200
Modern Tuscan EPS roof, EPS walls only	22,349	7,450	12,646	7,922	12,975	14,804	394	78,540
Modern Tuscan EPS floor & walls	22,349	7,450	9,224	9,219	13,859	14,804	394	77,299
Modern un-shaded flat IBR roof & ceiling	22,349	7,450	21,129	9,153	16,220	14,804	394	91,499

Energy Cost Summary (R / y)				
Alternative	**Total Electric**	**Total Utility**	**Incremental First Cost**	**PV Life Cycle Cost**
Modem or un-shaded Tuscan	R41,764	R41,764	R0	R644,558
Modern Tuscan EPS roof, floor & walls	R35,488	R35,488	R5,600	R553,298
Modern Tuscan EPS roof & floor	R37,600	R37,600	-R10,000	R570,293
Modern Tuscan EPS roof & walls	R39,269	R39,269	-R5,600	R601,652
Modern Tuscan EPS floor & walls	R38,649	R38,649	R25,600	R622,083
Modern un-shaded flat IBR roof & ceiling	R45,750	R45,750	R0,00	R706,075

Monthly Electrical Usage – (kWh)												
Alternative	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Modem or un-shaded Tuscan	6,736	5,776	5,941	5,775	7,280	9,795	9,763	7,785	6,198	5,934	6,091	6,453
Modern Tuscan EPS roof, floor & walls	6,656	5,766	6,403	5,280	5,443	6,066	6,146	5,813	5,543	5,807	5,909	6,470
Modern Tuscan EPS roof & floor	6,581	5,647	5,874	5,378	6,142	7,579	7,609	6,590	5,747	5,808	5,882	6,362
Modern Tuscan EPS roof & walls	6,670	5,732	5,897	5,415	6,556	8,693	8,678	7.021	5,796	5,763	5,923	6,395
Modern Tuscan EPS floor & walls	6,917	5,960	6,149	5,445	6,179	7,736	7,772	6,617	5,822	5,955	6,091	6,654
Modern un-shaded flat IBR roof & ceiling	7,113	6,169	6,543	6,656	8,150	10,267	10,315	8,759	7,109	6,805	6,698	6,916

Monthly Electrical Power Demand (kW)												
Alternative	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Modem or un-shaded Tuscan	19	18	17	21	27	32	32	28	25	17	18	18
Modern Tuscan EPS roof, floor & walls	17	16	16	15	15	19	19	18	15	15	17	16
Modern Tuscan EPS roof & floor	18	17	16	17	21	24	25	22	20	16	17	17
Modern Tuscan EPS roof & walls	19	18	17	18	23	28	28	24	21	16	17	17
Modern Tuscan EPS floor & walls	19	18	17	16	21	25	26	22	19	17	17	18
Modem un-shaded flat IBR roof & ceiling	18	17	16	24	30	36	35	30	28	19	20	16

Effect on air temperatures in an unoccupied house

The Building Toolbox/NewQuick software showed a decrease of maximum temperature of 7.1 ºC versus a concrete slab, and 11.0 ºC versus an IBR (Steel) roof and ceiling, compared to the combined three systems in place in an improved building.

The increase in minimum temperature was of the same order.

With an unimproved slab or with an IBR roof and ceiling the PPC was 0%. The PPC was 100% for the improved building at the hottest hour.

CONCLUSION

The reduction in energy usage as result of the combined EPS product/systems was 31.4 kWh/m^2 per annum. This is the expected reduction in combined heating and cooling energy load over a year expressed per unit area of the building. The reduction was attributed to the additional EPS insulation.

The individual effect of each measure was:

Wall Insulation	10.6 kWh/m^2.a
Floor Insulation	18.9 kWh/rn^2.a
Roof Insulation	15.8 kWh/m^2.a

When considered that the proposed SANS 204 Part 2 Deemed-to-satisfy requirement for energy usage in residential building in Johannesburg may be as low as 126 kWh/rn^2.a, it is evident that this represents a major area in which energy usage reduction can be achieved.

The reduction of peak electrical demand is over 40% for the cold winter months in Johannesburg. The reduction in heating demand can in some instances be complete. If windows are north facing and the building is not too deep, and if south facing windows are significantly reduced, then the heating can be eliminated completely even for a temperate climate such as Johannesburg, but certainly in total for milder climates such as for Pretoria and Cape Town.

The annual energy usage reduction with all EPS measures applied was just under 33% of those impacts which can be influenced by the shell of the building, for the region. In relation to a base-case of a building with an un-insulated ceiling and IBR (Mild steel) roof the reduction is 44%.

***Acknowledgement:* All calculations provided by Structatherm Projects**

ANNEXURE A

The 400 m^2 residence was assumed to be naturally ventilated and heated and cooled to comfort. However, in order to model the building using modern building simulation techniques and software it was necessary to assume that fan-powered fresh air was introduced, in this case, at the rate of 1.3 air-changes per hour.

Wall height was assumed to be 2.92m on average with internal ceilings at 2.40m. The roof was minimally sloped and of reinforced concrete design.

Fenestration: Glazing was assumed to be clear 3mm float glass, single pane windows in aluminium frames having a shading coefficient of 1.0 and Solar Heat Gain Coefficient of 0.86. There was minimal shading of windows in the design. Window areas were assumed to be slightly in excess of 20% of floor area.

Walls: The walls were assumed to be constructed of 100mm common bricks with the construction detail shown in Table 1. As shown, construction details in the improved building assumed 40mm of expanded polystyrene in a wall cavity. This level of insulation corresponds with the present SANS 204 Part 2 deemed-to-satisfy levels.

Roof Construction: Roof construction was assumed to be a concrete roof with screed to falls and built-up waterproofing, coloured to achieve an absorption co-efficient of 0.7.

The improved building had an EPS 255 insulated and reinforced concrete rib and block roof system.

Both cases had a decorative 9.6mm plasterboard ceiling installed on timber battens under slab.

Floor insulation: The base case floor slab was not insulated. As the building was heated via under-floor heating the slab was insulated with 40mm of high density EPS. The foundation of the building was also protected to a minimum depth of 300mm with 40mm of Expanded Polystyrene thermal insulation for the improved case.

Table 1 - Wall Construction Detail (Base case)

- 100 mm face brick
- 100 mm common brick
- 10 mm cement/sand plaster (R-value = 0.38 m^2K/W)

Improved building

- 100 mm face brick
- **40 mm Expanded Polystyrene**
- 100 mm common brick
- 10 mm cement/sand plaster (R-value = 1.38 m^2K/W)

Table 2 - Roof Construction Detail (Base case)

- Waterproofing
- Screed to falls
- 255 mm high density reinforced concrete slab
- 9.6 mm plasterboard ceiling (R-value = 0.55 m^2K/W)

Improved building

- Waterproofing
- Screed to falls
- **255 EPS insulated reinforced concrete slab**
- 9.6 mm plasterboard ceiling (R-value = 2.08 m^2K/W

Building Facades: The window lay-out assumed a standard window dimension 0.91 x 1.68m which was distributed evenly at 10.3m^2 to each facade, in all cases.

Lighting was designed to an overall power of 15W/m^2

Exterior Lighting: The Base-case exterior lighting was assumed to have a total connected load of 0.2kW. This was based on four 50W HPS lamps for the building perimeter. The improved case required four 19W compact fluorescent lamps with light sensors.

Appliance & Plug Loads: A value of 5 W/m^2 was assumed for the plug load value for both the improved and the Base-case. This covered all appliances and a swimming-pool.

Heating & Cooling Equipment performance, characteristics & sizing: The house was assumed to be served for cooling by a ceiling concealed DX split unit and resistance heating. A COP of 1.0 (EER=3.413) was assumed for the split units. Base-board heating of 2.0kW was provided in each of the ten interior zones.

Domestic Hot Water: Domestic hot water was provided by electric resistance water heaters. The installed heating capacity was 4kW for each of two 200L geysers.

Air flow rates were calculated by the software. Fresh air requirements were set to 1.3 air changes per hour.

An average occupancy density of 25.0 m^2/person was assumed.

Operation Schedules: An operating schedule appropriate to a residential occupancy was selected. There was no heating or cooling setback temperature, and it was assumed that the plant would be off during unoccupied hours.

Set-point temperatures: The set point temperature for heating was 20ºC, and for cooling 27ºC This was in line with a 7.0ºK range around an annual thermal neutrality of 23.5ºC. The throttling range about this set point was 2.0ºK. Thus heating would commence between 21 and 19ºC, and cooling between 26 and 28ºC. The dead-band between the temperatures 21 and 26ºC was within the tolerance of 80% in individuals for naturally ventilated structures. The building would go out to 19 or 28ºC on occasions which would be of short duration. This arrangement would reasonably simulate a naturally ventilated environment.