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# INFLUENCE OF DENSITY AND THICKNESS ON POLYSTYRENE INSULATED CONCRETE BLOCK WALLS

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**ABSTRACT:** Expanded polystyrene is known of its useful thermal properties and is widely used as an insulation material. Optimum performance depends on the design and selection of a product. Density and thickness of polystyrene boards were investigated using two chambers built of concrete blocks. The chambers were in the form of four block walls 20 cm in thickness, 1m by 1m size and 1m in height. Wood boards were used in roofs. The two chambers were identical except for insulation arrangements of the blocks. One chamber was built using bricks without insulation while the other chamber involved polystyrene insulated block walls. .In order to assess the influence of density; two types of materials were considered; Wall-mate polystyrene of an average density 26 to 28 Kg/m$^3$ and Roof-mate polystyrene of an average density of 32 to 35 Kg/m$^3$. Boxes of 60 cm x 60 cm x 60 cm made of polystyrene sheets were fabricated with thicknesses of 4, 5, 8 and 10 cm. Ambient temperature and temperature inside each chamber or polystyrene box were recorded using 5TE sensors and a data logger. Hourly records through specified periods of time were logged for the insulation systems used. Temperature changes within the chambers were studied and the influence of the board thickness and material density were reported. It was found that low-density polystyrene provides better insulation. Improvement due to a thickness of polystyrene boards was noted. The results provide a helpful guide for the specification and design works using polystyrene material.

*Keywords: Polystyrene, Temperature, Insulation, Thickness, Density.*

## 1. INTRODUCTION

This study is focused on the influence of the density and the thickness of polystyrene sheets when used for insulating cement blocks. Materials having better thermal properties and used in the construction industry include mineral wool, polyurethane, and polystyrene of various types. The expanded form of polystyrene is known as EPS, and the extruded form is known as XPS. The XPS is manufactured using extruders while EPS is manufactured by containing small foam beads. Expanded polystyrene is more used in insulation industry and considered the second popular insulation material in Europe and many other countries [1]. Many factors were reported to influence the flow of heat through materials. These include moisture and air humidity. Prediction of insulation level will not be valid without considering a set of factors. Reference [2] mentioned material composition, structure, density, porosity, and grain geometry and pore or opening size as main factors governing heat conduction. These factors can be observed in cement sand building materials. Density and air within EPS, the thickness of the board plus the overall settings of the insulation system may have their influence.

The main objective of this research is to construct a model chamber of concrete blocks and observe various methods of insulation using polystyrene. Previous research conducted by the authors [3] presented a comparison between non-insulated concrete blocks and insulated concrete blocks when used for model chambers of 1m by 1m and 1m height covered by a wooden roof and placed on a concrete grade slab. The study concluded that the improvement provided by the polystyrene cement blocks is less efficient in hot temperature than in moderate temperature. The insulation provided by the blocks as constructed is very poor and heat transfer is enabled through mortar filled gaps and joints. It is therefore recommended to consider an external or internal tanking using the EPS boards rather than depending on insulated blocks.

It is common practice to examine or test the thermal properties of newly introduced construction material [4] and [5]. This study follows a similar approach in order to highlight the efficiency of polystyrene insulated cement blocks. Testing for thickness or density alone may not be useful without considering the settings of the overall insulation system. Insulating a single side of the room while leaving another side not insulated will let the thickness of the polystyrene board insignificant. The insulation efficiency is judged based on the measured temperature inside a closed chamber. External factors likely to have a role in the thermal quality of the inside of the chamber include roof type and floor material. As the ambient temperature fluctuates within a specific range between day and night, the insulation materials are expected to narrow this range. Gain and loss of temperature normally take time depending on the insulation system. The research study is designed to measure the influence of thickness and density of polystyrene for a particular setting where cube chambers of 60cm x 60 cm x 60 cm placed near the ground with a temperature sensor placed inside and mid-point space of the cube.

Fig. 1. V-groove polystyrene-filled block

## 2. MATERIALS AND TESTING PROGRAM

The polystyrene boards used in this investigation were tested for the thermal conductivity and the effects of weather over six month period.

HFM 436 Lambda flow meter was used to measure the thermal conductivities for three samples. HFM 436 shown in Fig.3 is a calibrated instrument which performs tests I accordance with ASTM C518 and other standards [6]. The procedure involves a sample placed between hot and cold plate, and heat flow created by a well-defined, temperature difference is measured with a heat flux sensor.

Two chambers of 1m x 1m x 1m were built using commercial cement blocks of dimensions 200mmx250mmx400mm. One chamber is built with non-insulated blocks while the other chamber is constructed using blocks as shown in Fig. 1.

A previous study [3] showed poor insulation results due to gaps between blocks filled with mortar. It was recommended to use overall tanking using polystyrene. The 4cm Wall-mate material was used to cover the sides of the insulated chamber as well as the roof. Two chambers constructed in an open yard of the college of civil engineering in King Saud University. The chambers were 1m x 1m x 1m covered on top with a plywood board. As it was decided to follow the settings in practice the construction was made similar to the procedures carried out in the field. Mortar prepared with 1:2 water-cement ratio and 1:2 cement-sand ratio was used. Layers of thin mortar were spread in between block rows. The walls were left without plastering. In order to assess the influence of thickness and density on the insulation process, two types of polystyrene boards were utilized. These are Wall-mate type and Roof-mate type. The Roof- mate sheets are of a higher density quoted as 32 to 35 $Kg/m^{3.}$ Wall-mate polystyrene sheets are of average density 26 to 28 $Kg/m^3$. 60 cm x 60 cm x 60 cm boxes made of polystyrene sheets were fabricated with polystyrene thickness of 4, 5, 8 and 10 cm.

A set of four boxes of polystyrene two Roof-mate with 4cm and 5 cm in thickness and two Wall-mate with 4cm and 5cm in thickness were tested in the first stage, Another set of four boxes of polystyrene, two Roof-mate with 8cm and 10 cm thickness and two Wall-mate with 8cm and 10cm thickness were tested in the second stage.

Fig. 2. Two constructed chambers with a set of four polystyrene boxes.

Fig. 2 presents the two chambers as constructed with a set of four polystyrene boxes. Arrangements were made to have equipment for recording temperature inside each chamber and also ambient temperature.

5TE Decagon sensors register variations in temperature, volumetric water content, and electrical conductivity and all sent to Em50 data logger. The sensors were set to take records every one-hour intervals. The sensors were placed right in the centroid of the chambers or cubes. The expanded polystyrene, EPS material utilized in the insulation of cement blocks is placed between two parts of the block. The V groove provides an interlock with the block concrete. The coefficient of thermal conductivity is reported in the range of 0.045 ~ 0.065 W / (m k). This type of insulation is widely used in India, Southeast Asia, the Middle East, and other countries [6].

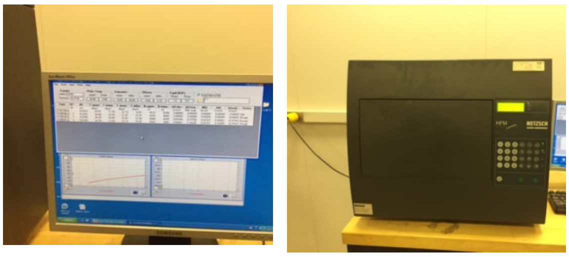

Fig. 3. Thermal conductivity Measurements HFM 436 Lambda flow meter

## 3. TEST RESULTS AND GENERAL DISCUSSION

Thermal conductivity measurements carried out for typical boards of new polystyrene and exposed polystyrene subjected to weather conditions over six month period were found 0.033292 W/mK and 0.033458 W/mK respectively indicating an increase of 0.5% approximately.

Temperature records obtained for comparing non-insulated block chamber and the chamber built using insulated blocks and covered with 4 cm thick polystyrene sheets indicated that the ambient temperature range over a 24 hours period can be reduced from 20 ºC to 8 ºC in the non-insulated block chamber. The insulated block chamber indicated a very narrow range of less than 5 ºC. Fig. 4 showing ambient temperature compared to the temperature measured for the two main chambers.

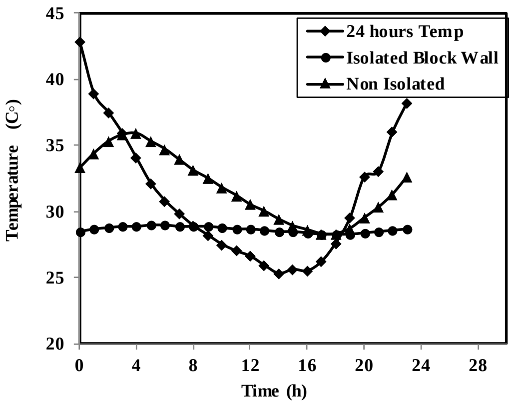


Fig. 4. The temperature profile for an insulated and non-insulated brick wall.

Fig. 5 presents a comparison between the main two types investigated in this research; the dense roof-mate and the less dense wall-mate polystyrene. Two thicknesses were considered for each type; 4cm and 5cm. The inside of the polystyrene cubes was found within 2 to 3 degrees cooler or hotter than the outside temperature. This is due to the time needed for gain and loss of heat. The polystyrene cubes were subjected to the ambient temperature but likely influenced by the ground temperature where the boxes are placed. A close-up view was shown in Fig. 6 for a three hours period when the ambient temperature was dropping from above 40 degrees to less than 37 ºC. The 4 and 5 cm thick roof-mate polystyrene remained hotter and very slowly losing heat compared to the 4 and 5 cm thick wall-mate polystyrene. One cm difference in thickness indicated an approximate difference of 0.75 ºC. The very dense roof-mate polystyrene is of lower thermal conductivity compared to the wall-mate which is less dense. This is found in agreement of the measurements carried out by reference [1] which showed that the thermal conductivity coefficient is indirectly proportional to the density. The polystyrene alone was found to reduce outside temperature by 2 degrees only compared to 7 ºC for polystyrene and brick wall together. The influence of polystyrene thickness is clearly indicated. Each one cm thickness can introduce a difference of 0.75 ºC approximately for both roof-mate and wall-mate types.

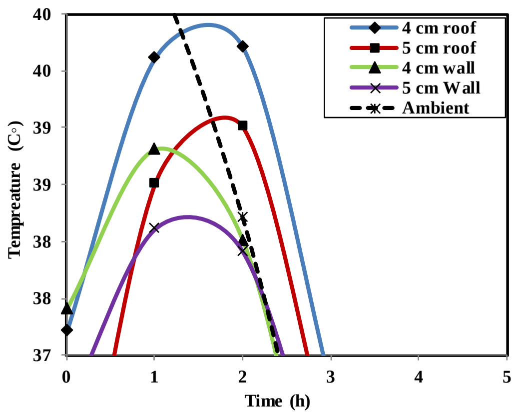


Fig. 6. View of temperature records as compared to 4 and 5cm thickness and two types of polystyrene

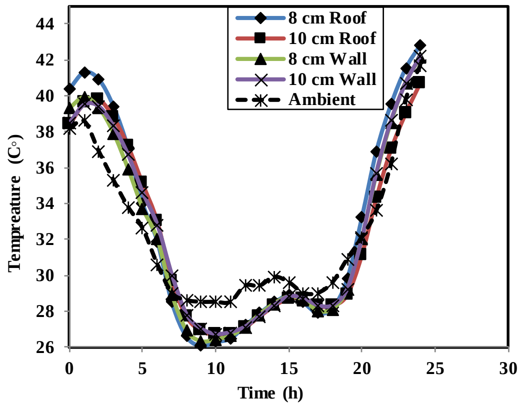


Fig. 7. Ambient temperature compared to 8 and 10 cm thickness and two types of polystyrene.

Fig. 7 also presents a comparison between the main two types investigated in this research but for an extra set of thicknesses. Two thicknesses were considered for each type; 8 cm and 10cm. The inside of the polystyrene cubes was found within 2 to 3 degrees cooler or hotter than the outside temperature. A close-up view was shown in Fig. 8 for two hours period when the ambient temperature was dropping from about 38.5 to less than 37 degrees. The 8 and 10 cm thick roof-mate polystyrene remained hotter and very slowly losing heat compared to the 8 and 10 cm thick wall-mate polystyrene. Two cm difference in thickness indicated an approximate difference of 1.5 to 2.0 degrees. The influence of polystyrene thickness is clearly indicated and almost doubled when compared to the set of 4 and 5 cm group of polystyrene boxes.

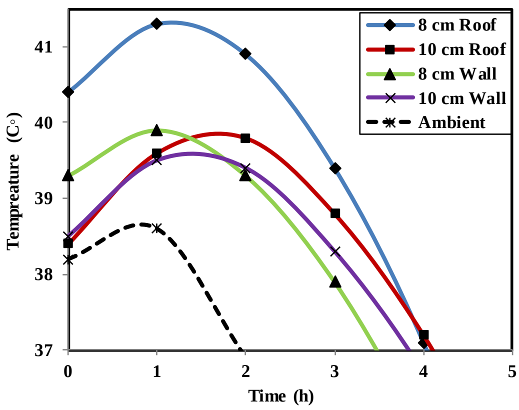


Fig. 8. View of temperature records as compared to 8 and 10 cm thickness and two types of polystyrene.

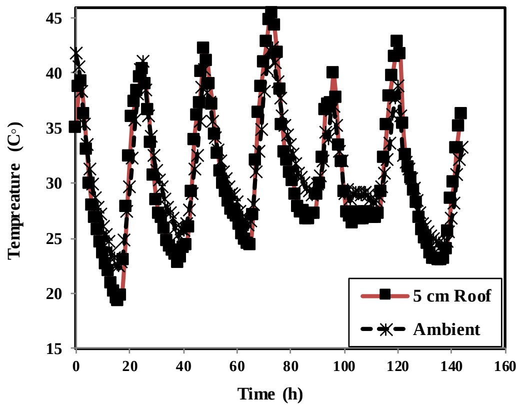


Fig. 9. Daily temperature variation over 6 days

Fig. 9 presents six days temperature variations. The minimum temperature reported was 20 degrees and the maximum was 45 degrees. The difference between ambient temperature and the inner of 5cm roof-mate boxes was about 2 degrees.

The average high and average low-temperature profile for six month period is presented in Fig. 10.

It can be observed from the curves presented in Fig. 9 that the variation in temperature is influenced by the ambient temperature. In other words, the thermal conductivity of the polystyrene is dependent on the value of ambient temperature. This is not different from what quoted by reference [8] which stated that operating outside temperature affect the thermal conductivity of polystyrene insulation material.

Measurement carried out by reference [1] showed that the thermal conductivity coefficient is indirectly proportional to the density. The thermal conductivity is between 0,036 and 0,046 W/mK, for densities of expanded polystyrene between 10 and 30 kg/m3. Water absorption was measured as 3.5% for 30 kg/$m^3$ and 5.5% for 15 Kg.

The properties of expanded polystyrene are influenced by the state of packing and manufacturing process. However, the present study is concerned with the density and material thickness of a selected commercial product. This is not necessarily typical for other materials as the form and fabric of polystyrene may be different. The trend will remain the same but the measurements can be variable and little different. The overall external or internal tanking is encouraged as the losses through other materials proved to be significant when the used materials are of poor thermal conductivity properties.

The foam boards of polystyrene are manufactured by pressing styrene resin polymer material (Extruded Polystyrene- XPS) or by using steam and pressure to compress polystyrene grains into predesigned molds [9]. Level of applied pressure can determine the required density of the board.

Here it worth mentioning that the thermal conductivity obtained by optimizing density and thickness alone may not be sufficient. The structural performance of the board and its resistance to weather conditions must be investigated. Tough boards used to protect roof must be assessed based on live load assumed for accessible or non-accessible loads. Unit weight in production is varying between 10-36 kg/$m^3$ and production densities are normally quoted within ranges of 2 to 5 kg/$m^3$ (i.e 10 to 12 or 10 to 15 kg/$m^3$).

The polystyrene boards were found cost-effective and lightweight due to the high air content. Expanded polystyrene proved to be stable and can maintain firm shape and fabric as well as acceptable physical appearance. These features make the product durable and able to sustain extended life cycles.

Manufacturers of EPS claim that their materials produce no ozone-depleting gases. The chlorofluorocarbons (CFCs) are not used in the process.

The EPS can be recycled by shredding and adding it to the thermoforming process. Up to 20%, shredded EPS can be added to virgin EPS pearls before thermoforming without any quality loss [10] Reference [10] indicated that shredding EPS can be done more than 5 times, and then the material can be replaced by virgin pearls. All types of EPS can be mixed together during recycling. This is expected to introduce some changes to the new product. The thermal conductivity can be checked for each recycled patch.

A previous study conducted by the first two authors investigated the efficiency of polystyrene insulated cement blocks in arid regions. The study given in reference [3] concluded that the polystyrene insulated cement blocks behave differently for different temperature gradients and different levels of heat. However, this study did not address the main parameters covered in this research.

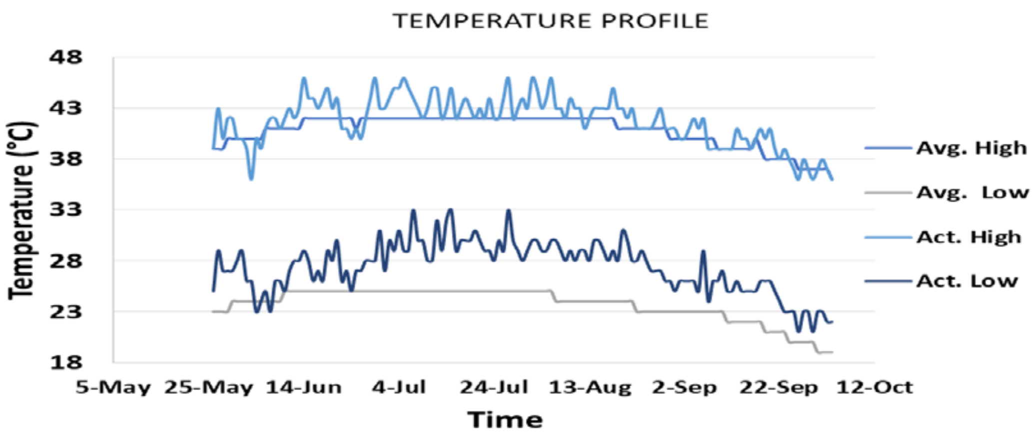


Fig. 10. Average high and low temperature over six month period.

## 4. CONCLUSIONS

The insulation of heat utilizing EPS polystyrene in the construction industry is dependent on the method and setup selected as well as the physical properties of the materials. The denser polystyrene used in roof-mate insulation system was found to have lower thermal conductivity when compared to the less dense wall-mate polystyrene. An average of one cm thickness was found to result in 0.75 °C temperature difference from the ambient temperature. This is based on the extreme ambient temperatures for the tested environment as polystyrene shows different characteristics for different temperature gradients and different levels of heat exposure. Exposure to the environment was found to impact the thermal conductivity of polystyrene. The influence of thickness and density must be considered in view of the insulation method adopted and the ambient environmental conditions.

## 5. ACKNOWLEDGMENTS

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