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Thermal Assessment of a New Bio-Based Insulation Material

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Abstract

In recent times, the building sector is moving towards new approaches to energy-efficient design "low energy consumption". The development of bio-based thermal insulation materials contributes to such approaches; their implementation in the building gives a good result in a reduction of energy demand. Moreover, another beneficial environmental portion such as the reduction in the depletion of non-renewable resources and in waste generation. Using thermal insulation in the building envelope can substantially reduce the building's thermal load and consequently its energy consumption. Thermal insulation is organic or inorganic material, manufactured to reduce the propagation of the heat by a combined heat transfer (i.e., conduction, convection, and radiation). More advanced insulation materials have been recently developed. However, most of the available insulations are not eco-friendly and may require a huge amount of energy and complex manufacturing processes to be produced. Some commercialized bio-based thermal insulation materials are currently available, such as industrial fibers hemp, flax, kenaf. Also, recently some researches are conducted to develop thermal food-crop by-product insulation from palm date, pin apple leaves and rice husk. However, production cost and lower thermal resistance are the main correlated issues. A new cheap bio-insulation material with huge commercialization potential and environmental footprint is proposed. The main idea of running a project is to develop a new material, which is environmentally friendly insulation from grain. The early experiments of the insulation product showed a similar or even better thermal performance that could compete with common insulation materials such as polystyrene.

Keywords: Bio-Based Insulation; Thermal Conductivity; Environmentally Friendly

Introduction

Buildings are the largest consumer of energy among other sectors. One of the most important challenges of future buildings is the reduction of energy consumptions in all their life phases, from construction to demolition. Global energy consumption is foreseen to be increased by 53% within the next ten years from the International Energy Agency (IEA) prediction, which is as the result of the significant increase in industrial and urban activities due to the intensive country development and dramatic increase of population size in the recent times. The United

Nations Environment Program estimates that buildings consume about 40% of the world's global energy. In the UAE, buildings account for a major share of electric energy consumption. Some existing buildings in the UAE consume 220-360 kWh/m^2/year [1]. Building air-conditioning and ventilation systems due to prevailing extremely hot climatic conditions use almost 80% of this energy [2]. Therefore, it is significant to search for solutions to reduce energy consumption in buildings [3].

Due to the increasing population energy consumption in the sector of building and the hard-economic situation, it is necessary to control energy during the building process. To achieve an accurate cooling/heating load calculation for buildings, an analysis of conductive heat transfer through the material is very important in energy-efficient building design. Thus, the knowledge of thermal properties and precise evaluation of the heat transfer through the envelope components, particularly thermal conductivity of material construction, are of great importance. This depends mainly on the accuracy of the thermal resistance of the different building envelope components, particularly the insulation materials. It is a layer composed of one material or combination of materials. According to its structure, Papadopoulos classified the insulation material to organic, inorganic, combined and new technology materials [4]. A new classification proposed by Li Fang categorizing the insulations into four main denominations: i) petrochemical & intermediate charcoal chemical material such as Polystyrene and Polyurethane, ii) rocks and slags: glass wool and expanded perlite, iii) metals: radiation plate and metal visor, iv) plants, which include the waste of agriculture, forest, and industrial plant fiber: cotton, corn crops, straws [5].

The implementation of appropriate effective insulation materials could contribute to lower energy consumption and decreases the usage of natural resources (petroleum/gas reserves) which are used for cooling purposes [6]. Also, it essentially contributes to the overall thermal performance of the walls [7-8] possesses the characteristic of high thermal resistance, which exhibits the capability to reduce the heat flow rate into the buildings [9] due to specific thermos-physical properties [10]. However, more consideration should be given for its negative health and environment effects in both the production process and the disposal phases of end-of-life products [11]. Industry Analysis Building Thermal Insulation Market reports that using some insulation materials (glass wool) can lead to environmental issues due to the consumption of nonrenewable materials and end-life processes [9]. Therefore, new "bio-based insulations" have been introduced as thermal insulation products made of natural materials [12-16]. The most common ones are hemp, cotton, sheep wool, flax, linen, and kenaf fibers [5].

The thermal resistance of the bio-based insulation materials is mainly lower than the non-bio insulation materials as well as their structural strength. In a hot and arid climate, the thermal insulation materials comprising the building envelope are exposed to significant and continuous temperature and moisture changes due to the variations in the external conditions, including the outdoor temperature, solar radiation, and air moisture content, which leads to the change of their thermal resistance values [17]. Indeed, the accuracy of the thermal conductivity (k) of the insulation material, which describes the ability of heat to flow across the material in the presence of a temperature gradient, has an important effect on the heat exchange between the building interior and the ambiance. For most materials, the value of thermal conductivity increases as the influencing temperature increases. Therefore, temperature-dependent thermal conductivity is an empirical relationship that is based on experimental data [18]. One of the potential problems faced by building designers when calculating the cooling loads or analyzing the energy performance of any building, is the using of published or manufactures supplied values of thermal conductivity of building insulation, which are evaluated under specific laboratory conditions at 24 °C, according to the American Society for Testing and Materials (ASTM Standards).

In reality when it comes to UAE, hot and arid climate. the thermal insulation materials comprising the building envelope are exposed to significant and continuous temperature and moisture changes through the day and over the seasons, due to the variations in the external conditions, including the outdoor temperature, solar radiation, and air moisture content, which leads to the change of their thermal conductivity values. The impact of temperature difference on the thermal conductivity of some insulation materials produced by Saudi insulation manufacturers has also been investigated [19]. In addition, the effect of operating temperature change on the thermal conductivity of polystyrene insulation material has been studied extensively by the author [17,20] concluding that the thermal conductivity of four different density levels of polystyrene samples is affected by the operating temperature linearly. The material moisture content, on the other hand, has been considered a major factor affecting the thermal conductivity of insulation materials [21]. Many researchers reported the effect of the moisture on the heat transfer through building insulation material concluding that the higher the material moisture content, the higher the thermal conductivity [22-24]. The research aims to propose a new bio-based insulation material from grains and thermally evaluate its performance compared with the standard insulations in both dry and humid extreme temperature exposure to be suitable to deploy in hot-humid climates as of UAE.

Methodology and Experiment Setup

In order to have a better understanding of the cooling performance of the new bio-based insulation material in buildings, well-designed experiments and simulations well carried out. At this stage, the standardized experimental methods have been adopted to produce a novel insulation from the grain by investigating the different types of materials to be used as insulation then applying different production process to achieve the proposed new bio-insulation. The sample of the new bio-insulation material will be test and analyze to confirm the thermo-physical properties of the proposed new bio-insulation material and compared with some available insulation material (EPS): first, the thermal conductivity measurements at standardized conditions for some of the existing insulation material have been conducted to verify their catalogue data as a reference. Secondly, the thermal conductivity values of the proposed bio-insulation material have been tested and the thermal performance of proposed new bio-insulation material and the existing insulation material have been evaluated by employing various temperatures and humidity ratios. The raw material of the proposed new bio-insulation (grain) has been collected, dried out, adjust the moisture content and exposed to certain temperature and pressure values to produce the insulation samples. To control the grain moisture level a specific amount of water had been add to the grain and then tested by the moisture analyzer to adjust the desirable moisture percentage as shown in Figure 1.

Figure 1: Moisture Analyzer Device to Control the Moisture Level of Raw Material.

The machine used in the production of these new bio-insulation samples has small gear-shaped motor, driven by protruding wheel, and has temperature controller, can automatically control the machine and retain the machine under a constant temperature as well as pressure control to adjust the pressure. The produced bio-insulation samples have been evaluated thermally by testing its thermal conductivity value applying heat flow that passes through a unit area of a 1 cm-thick sample material with the temperature gradient from 5°C-45°C using the commercial Laser Comp Heat Flow Meter Instrument (Fox200).

Results

In the production process of the bio-insulation material, the grains were collected and some parameters were tested to be optimized like the moisture level of the raw material and the temperature value in the production process as shown in Table 1.

Moisture [%]	Temperature [°C]	Thickness of the Sample [cm]
18	260	1.1
16	240	0.9
14	220	0.8

Table 1: Proposed Bio-Insulation Material at Different Moisture and Temperature.

The thermal conductivity of dry samples of the new proposed bio-insulation was compared with the low-density polystyrene as shown in Figure 2.

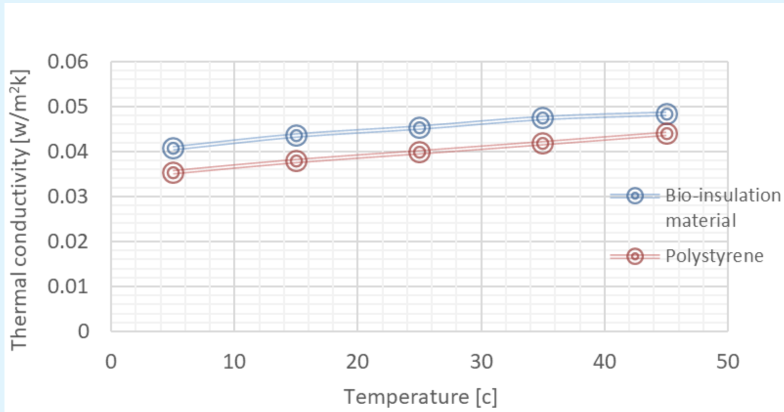

Figure 2: Thermal Conductivity Variation of Bio-Insulation and Polystyrene.

Discussion

The obtained experiments showed that the raw material of 18% of moisture and temperature of 260°C present the most porosity and biggest thickness as compared with other samples with 14% moisture and temperature of 220°C with 1 cm and 0.8 cm thickness respectively, as described in Table 1. The early experiments of the insulation product showed a similar thermal performance to other insulations, by testing the thermal conductivity k-value for the new bio-insulation material and compared it with the other available insulation thermal conductivity k-values. The results showed that the new proposed bio-insulation competes with common insulation materials such as polystyrene; the thermal conductivity at 45°C is 0.04839 and 0.04395, respectively.

Conclusion

The new proposed bio-insulation has a huge commercialization potential. Moreover, its bio characterization makes it an environmentally friendly material to use in the building sector. Further investigations will be performed such as moisture level, temperature pressure and binding material. Some other physical properties should be improved including the thermal resistance and the structural features.

Conflicts of Interest

The authors declare no conflict of interest.

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