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IMPROVING BUILDINGS ENERGY CONSUMPTION IN EGYPT BY APPLYING NANO-BASED THERMAL INSULATION MATERIALS

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ABSTRACT

In order to serve the Egyptian national energy saving policy ultra-energy saving technologies are desperately needed to be applied. Nanotechnology produced advanced insulating materials that have been applied in many industrial fields. Last decade several Nanotechnology-based thermal insulation materials (NBTIM) have been globally applied in the building sector. This research aims to describe some advantages of using Nanotechnology-based thermal insulation materials in buildings and its applicability in Egypt. A comparative study is done between NBTIM properties and a sample of conventional thermal insulation materials with its various thicknesses that are currently used in Egypt. The 2D energy software is used to present the NBTIM application in buildings, and results showed that NBTIM provides better thermal insulation using less layer thickness than the conventional insulating materials. The research paper concludes by stating the challenges and benefits of using Nanotechnology-based thermal insulation materials in the construction and architecture market in Egypt.

KEYWORDS: Building energy consumption, Nanomaterial in Architecture, Thermal insulation.

1. INTRODUCTION

Global increase of energy demand accompanied by a foreseeable scarcity of fossil fuels is observed worldwide, causing a continuous increase of carbon dioxide emissions which leads to a climatic challenge. Hence, generation of power with provision of sustainability is a necessity. Nano technological components provide potentials for the optimum utilization of energy reserves and an economic development of renewable ones. Buildings are considered the largest energy-consuming sector in the world. It is consuming over one third of the global energy requirements, and having an important share of carbon dioxide (CO_2) emissions.

Nanotechnology is a new technology that tends to change the properties of natural materials by modifying its particles structure at the Nano scale in order to obtain a better functional performance. The use of Nanotechnology is very important to achieve many goals for example: getting the green gains for building, better energy saving, high performance, and lower operational costs. Nano technology opens new possibilities in the field of sustainable construction by offering a better use of natural resources to produce Nano-based materials. Nano-based materials have the capability to do the same or better functions using minor amounts of raw material.

Advanced materials such as these developed via the application of Nanotechnology and biotechnology offer efficient responses to environmental as well as economic issues in the industrial sector. Despite that, these materials were not technically studied and not implicated in the design process by architects except recently.

A traditional construction material like cement, steel, polymers, or glass is considered a Nano-structured material when it is mixed in surface or mass with Nano-composites, or when its physical and chemical structure is modified at the Nano-scale. When such material is modified its performance becomes incomparable to that obtained by the original material(Sanchez and Sobolev 2010).

When the physical-chemical properties of building materials as cement based and certain types of polymers and composite materials are observed at the Nano-scale, their properties can be tested at high degree of precision. Thus, it becomes possible to correct and optimize the characteristics of material’s Nano structures to improve the final performance without even the addition of Nano-materials.

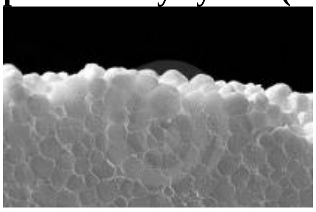
The objectives of using Nano-materials and Nano-systems in the construction sector are to make it more competitive with a high technological potential, environmental friendly, and secure(Hellsten 2005, Sanchez and Sobolev 2010). Using raw materials more rationally; reducing the cost of the product throughout its life cycle; and producing new materials with higher performance level, higher efficiency and durability are all considered relevant key issues to these objectives. The Nano structures control in building materials and the use of the special properties of Nano-materials introduces various products that have several functions: structure, envelope, coating, equipment, and sensors.

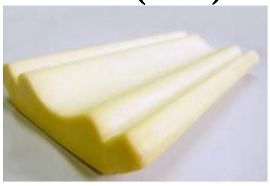
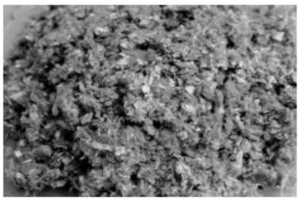
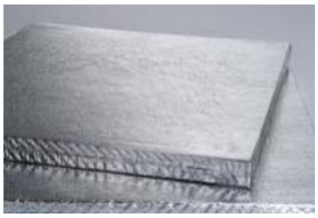
This paper focuses on introducing the concept of thermal insulation of buildings with its conventional material as well as the state of the art Nano-based materials that are known as Nanotechnology-based thermal insulation materials (NBTIM). A model comparison between different insulation materials with various thicknesses is performed. The challenges as well as the benefits of using the NBTIM in the construction and architecture sector in Egypt are discussed. The rest of the paper is arranged as follows; section 2 defines the thermal insulation in buildings and introduces several examples of materials used as insulators. Section 3 presents a model comparison of the heat transfer rate and thickness between conventional and NBTIM, it provides results and discussion for the findings of the comparison. Section 4 concludes the paper.

2. Thermal Insulation in Buildings

Building insulation means the use of some materials as thermal insulators in order to decrease the dissipated heat via the buildings walls. A large amount of energy is consumed to provide adequate temperature in buildings, thus thermal insulation will be beneficial to alleviate unwanted heat loss/gain and it will also assist in reducing the heating and cooling systems energy demands. Typically, the significant properties and the required characteristics of insulation materials are their light weight, their small density, and being porous. Concerning most of the inorganic insulation materials, they are inflammable, moreover; they have a wide range for heat insulation and they have good resistance to chemical corrosion. On the other hand, most of the organic thermal insulation materials are characterized by their high intensity and low ability to absorb water. Table 1 presents examples of conventional thermal insulation material as well as Nano-based state of the art thermal insulation material used in construction. Table 2 summarizes thermal conductivity, and the density of the insulation materials.

Table 1: Conventional and Nano-based Thermal Insulation Materials (Huang 2012).

Conventional Thermal Insulation Materials	
1- Mineral wool  **Figure 1. Scheme of Mineral Wool Material (Utochkina 2014), (Jelle 2011), (Rainey 2010).**	Mineral wool: fluffy short fibers made from natural mineral raw materials (Figure 1) that can be used in steel, concrete and masonry roofs, partitions and walls' insulation, as well as high temperature pipe insulation. Properties: low thermal conductivities values, about 30 to 40 mW· (mK)−1 at 10℃,non-combustibility, non-toxicity, good durability, heat resistance as well as corrosion resistance.
2- Expanded Polystyrene (EPS)  **Figure 2: Scheme of Expanded Polystyrene Material (Jelle 2011), (Dreamstime 2000-2018), (Ochs and Müller-Steinhagen 2005).**	Expanded Polystyrene (EPS) (Figure 2): made from expandable polystyrene, which is a rigid cellular plastic containing an expansion agent. EPS is widely used in building insulation and sound insulation, covering of side wall and inner wall. Properties: good shock absorption ability, low thermal conductivity of 30 to 40 mW· (mK)−1 at 10 ℃ high compressive resistance, low weight and its humidity resistance as well as low density of 40 Kg/m3.
3- Extruded Polystyrene (XPS)  **Figure 3: Scheme of Extruded Polystyrene Material (Jelle 2011), (Ochs and Müller-Steinhagen 2005), (Owens Corning Foam Insulation 2011).**	Extruded Polystyrene (XPS) (Figure 3): formed by extrusion process, due to which, extruded polystyrene has a more regular and well-arranged cell structure, smooth continuous surface and consistent qualities across all areas. Properties: thermal conductivity XPS are between 30 and 40 mW· (mK)−1 at 10 ℃,density of 40 Kg/m3, and a higher thermal insulation capability than other insulation materials, and better moisture resistance. The only problem is its flammability.
4- Cork  **Figure 4: Scheme of Cork Material (Anjos, Pereira et al. 2008), (Silva, Sabino et al. 2005), (Silvestre, Pargana et al. 2016).**	Cork (Figure 4): The bark of cork oak tree which is a renewable material obtained periodically from the tree. Properties: Low density (120~200Kg/m3) and high porosity ranging from 0.5 to 22%, very high acoustic resistivity, a general thermal conductivity of 45mW · (mK)−1 at 25 ℃ and thermal diffusivity of 1 × 10−6 m2s−1.

5- Polyurethane (PUR)  **Figure 5: Scheme of Polyurethane Material(Ochs and Müller-Steinhagen 2005), (Jelle 2011), (Europe 2015).**	Polyurethane (PUR) (Figure 5): is formed by a reaction of isocyanates and polyols (alcohols with multiple hydroxyl groups). Properties: a density of 40 ~ 60 Kg/m3, and thermal conductivity of35mW· (mK)−1 at 10℃, light weight (density adjustable), excellent thermal, sound insulation abilities, good chemical resistance and low water absorption.
6- Cellulose  **Figure 6: Scheme of Cellulose Material (LowEnergyHouse.com), (CIMA), (Europe 2015), (Lea 1996), (WordPress.com 2010).**	Cellulose (Figure 6): an organic compound formed from recycled paper or wood pulp. Cellulose products can be used in wall and roof cavities to separate the inside and outside of the building thermally and acoustically. Properties: good sound insulation, pest control property, fire retardation, vapor barrier, good thermal performance, density between 24 to 27.2 Kg/m3, and a thermal conductivity of 35 mW· (mK)−1 at 10℃.
Nano-material: State-of-the-art thermal building insulations	
7- Vacuum Insulation Panels (VIP)  **Figure 7: Scheme of Vacuum Insulation Panel (Jelle 2011), (Brunner and Simmler 2008).**	A vacuum insulation panel (VIP) (Figure 7): has three parts: membrane walls, to prevent air from getting into the panel; a panels from highly-porous materials like fumed silica, aerogel or glass fiber, to support the membrane walls against atmospheric pressure when the air is evacuated; and last some chemicals used for sealing of the membrane walls. VIP is well-used in building constructions because of its better thermal performance than other conventional insulation materials. Properties: thermal conductivity ranging from between 3 and 4 mW· (mK)−1 for the dry core at 1 mbar and 10℃ to an overall value of 8 mW· (mK)−1, high thermal resistance.
8- Gas-filled Panels(GFP)  **Figure 8: Scheme of Gas-filled Panel (Yarbrough, Petrie et al. 2007), (Institute 2016-2017), (Building Green 2010).**	Gas-filled panels or GFPs (Figure 8): consists of thin polymer films and low-conductivity gas, with extraordinary thermal insulation properties. Properties: about 36.1 mW · (mK)−1 for air, 49.2 mW· (mK)−1 for argon and 86.7mW· (mK)−1 for krypton , higher thermal conductivity. Therefore, VIP seems to be a better choice for insulation applications.

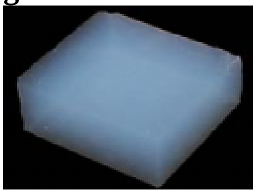
9- Aerogels  **Figure 9: Scheme of Aerogel Material (Isolazioni 2008-2011).**	Aerogels (Figure 9): the world's lightest solid materials composed of 99% air. Properties: synthetic porous material, very low density (3 Kg/m3), low thermal conductivity of 14 mW/(mK), as well as incredibly light weight and high specific surface area.
10- Phase change materials (PCM)  **Figure 10: Scheme of Phase Change Material.**	Phase change material (PCM) (Figure10): a substance with high heat of fusion which has a good ability of storing and releasing large amounts of energy. Properties: solid at room temperature, but after heated liquefy and absorb and store the heat thus cooling the buildings, solidify and release the heat to warm the buildings when temperature decreases, melting temperature above 25°C, low cost, non-toxic, non-corrosive, non-hydroscopic, and sufficient quantities.

Table 2: Summary of the insulation materials thermal conductivity and density (Johansson 2012), (Thermablok 2010).

Insulation materials	Thermal conductivity (mW/^{o}K)	Density(kg/m^{3})
Mineral wool	30-40 (at 10 ^{O}C)	30-200
Expanded polystyrene(EPS)	30-40 (at 10 ^{O}C)	40
Extruded polystyrene(XPS)	30-40 (at 10 ^{O}C)	100-150
Cork	45(at 25 ^{O}C)	120-200
Polyurethane(PUR)	35(at 10 ^{O}C)	40-60
Cellulose	35(at 10 ^{O}C)	24-27.2
Vacuum insulated panel(VIP)	3-4(at 10 ^{O}C)	-
Gas-filled panels(GFP)	36.1 for air	-
	49.2 for Argon	-
	86.7 for Krypton	-
Aerogel	13-16 at atmospheric pressure	3

(W means watts, °K means degrees. Kelvin, m means meters.)

2.1 Nano Based Thermal insulation materials properties

Nano technology application in the field of building thermal insulation has produced three major products, Vacuum insulation panels, Aerogel, Phase change material. Table 3 compares different properties of these three Nanomaterial thermal insulators.

Table 3: Comparison of Nanomaterial thermal insulators properties for VIPs, Aerogel, and PCMs.

Nano-based Thermal Insulation			
Product	**Vacuum Insulation Panels (VIPs)**	**Aerogel**	**Phase Change Materials (PCMs)**
Properties	Maximum thermal insulation. Minimal insulation thickness. The thickness range of panels is generally 10-50 mm.	High-performance thermal insulation. Effective sound insulation.	PCMs are invariably made from paraffin and salt hydrates.
Specifications	An enveloping skin made of plastic foil or of stainless steel. the fill material takes the form of foam, powder or glass fibers.	Light and airy Nanofoam. Aergel contributes towards energy efficiency.	Reduced heating and cooling demand. Passive temperature regulation.
Usage	Used both for new building constructions as well as in conversion and renovation work and can be applied to walls as well as floors. The lifetime of modern panels is generally estimated at between 30 and 50 years	Nanogel-filled glass panels are suitable for use in facades but also for interiors.	Conserving energy by reducing the energy demand for heating and cooling.

3. Insulation Materials Thickness Comparison

A model comparison is performed for thermal conductivity of a sample of conventional insulation materials and Nano-based Aerogel and Vacuum Insulated Panels. The internal heat transmittal is measured for each material related to its thickness using Energy 2D software. The findings are presented in Figures 13A, 13B, and 13C.

For the three comparisons of the heat transfer presented here under, the study duration is a 1 minute time interval, an interior uniform temperature of 20 ^{o}C is used. A wall build material and a common perorated bricks external layer of cement plaster of thickness 20 MM - U Value W/(M ^{o}C) 0.07 is employed.

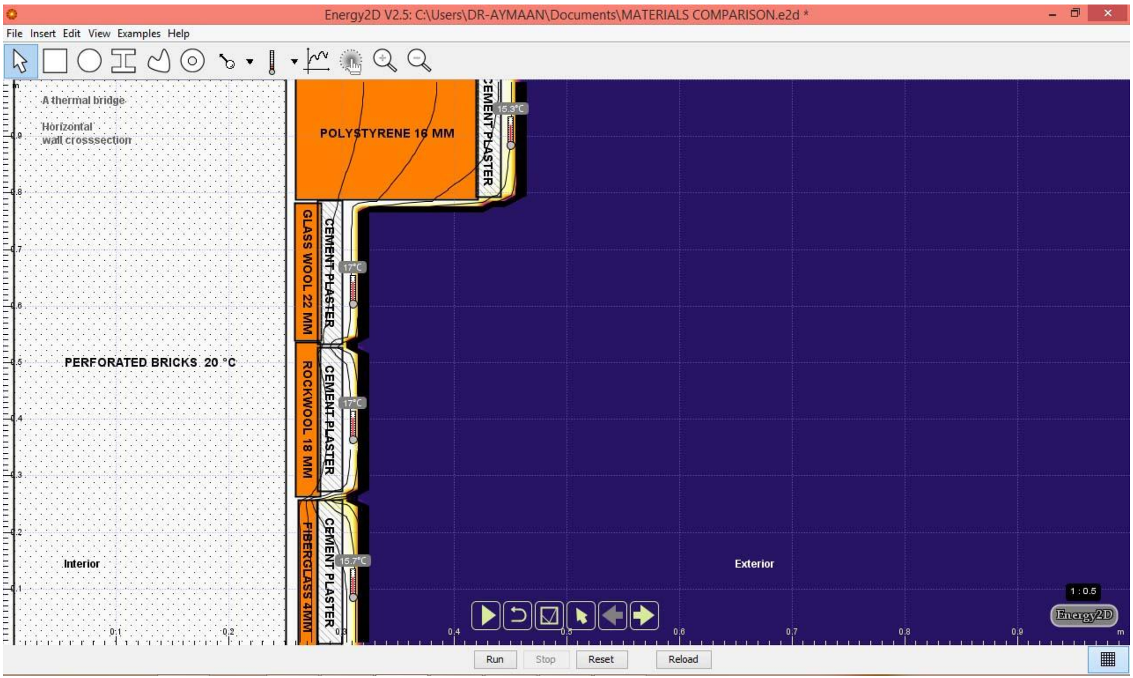


Figure 11: Horizontal cross section of four insulating materials for heat transfer comparison.

Figure 11 presents a horizontal cross section of four insulating materials layers; Polystyrene, Glass Wool, Rockwool, and Fiberglass when compared for heat transfer. The results of the comparison are shown in Table 4.

Table 4: Heat transfer comparison results for Polystyrene, Glass Wool, Rockwool, and Fiberglass.

Material	Thickness mm	U Value W/(M°C)	Outside Surface Temp after 1 minute
Polystyrene	16	0.156	15.3 °C
Glass Wool	22	0.052	17 °C
Rockwool	18	0.048	17 °C
Fiberglass	4	0.04	15.7 °C
Thermal conductivity values are those of the C4 National Building Code of Finland – Thermal Insulation Guidelines 2002			

The results obtained in Table 4 show that the Fiberglass has the least thickness of 4 mm with the lowest thermal conductivity of U Value of 0.04 W/(M °C). It is also observed that Polystyrene gave the highest U Value W/(M °C) of 0.156 with a higher thickness of 16 mm.

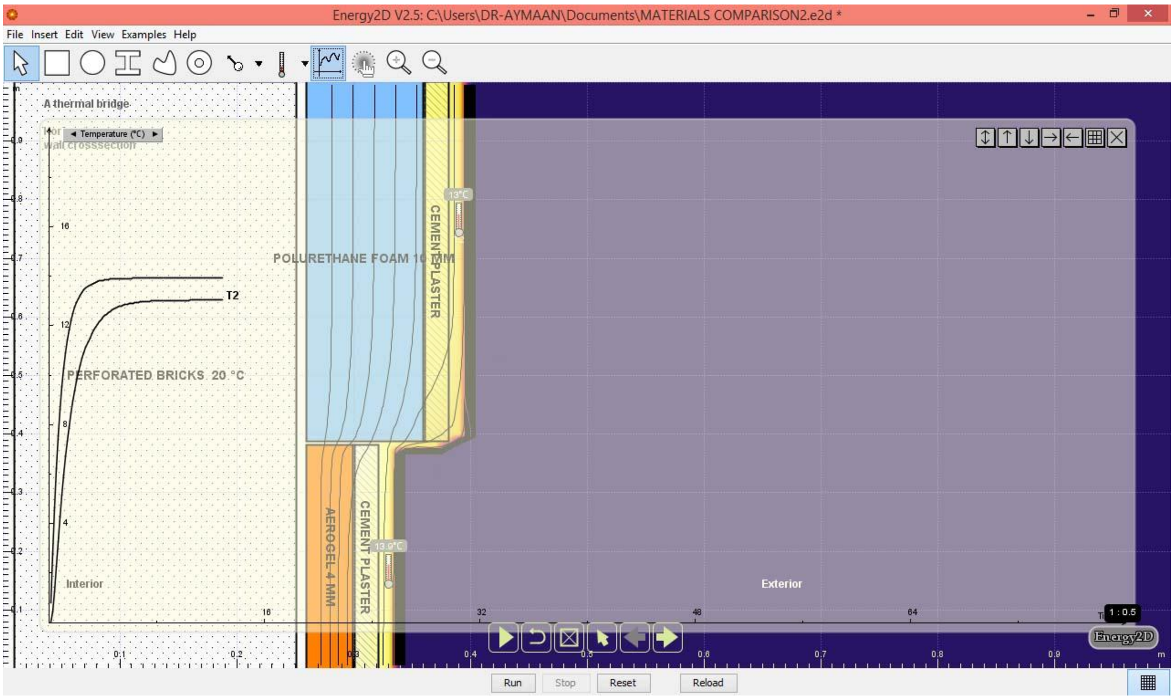


Figure 12: Horizontal cross section of two insulating materials for heat transfer comparison.

Figure 12 depicts horizontal cross section of Nano-based Aerogel and conventional Polyurethane Foam for the heat transfer comparison for 1 minute time interval. The results of the comparison are shown in Table 5.

Table 5: Heat transfer comparison results for Nano-based Aerogel and conventional Polyurethane Foam.

Material	Thickness mm	U Value W/(M^{o}C)	Outside Surface Temp after 1 minute
Poliutrethane Foam	10	0.1	13°C
Aerogel	4	0.03	13.9°C
Thermal conductivity values are those of the C4 National Building Code of Finland – Thermal Insulation Guidelines 2002			

The results obtained in Table 5 show that the Nano-based Aerogel has the least thickness of 4 mm with the lowest thermal conductivity of U Value of 0.03 W/(M ^{o}C). It is observed that Nano-based Aerogel layer of thickness 4mm is equivalent to 10 mm of conventional Polyurethane foam.

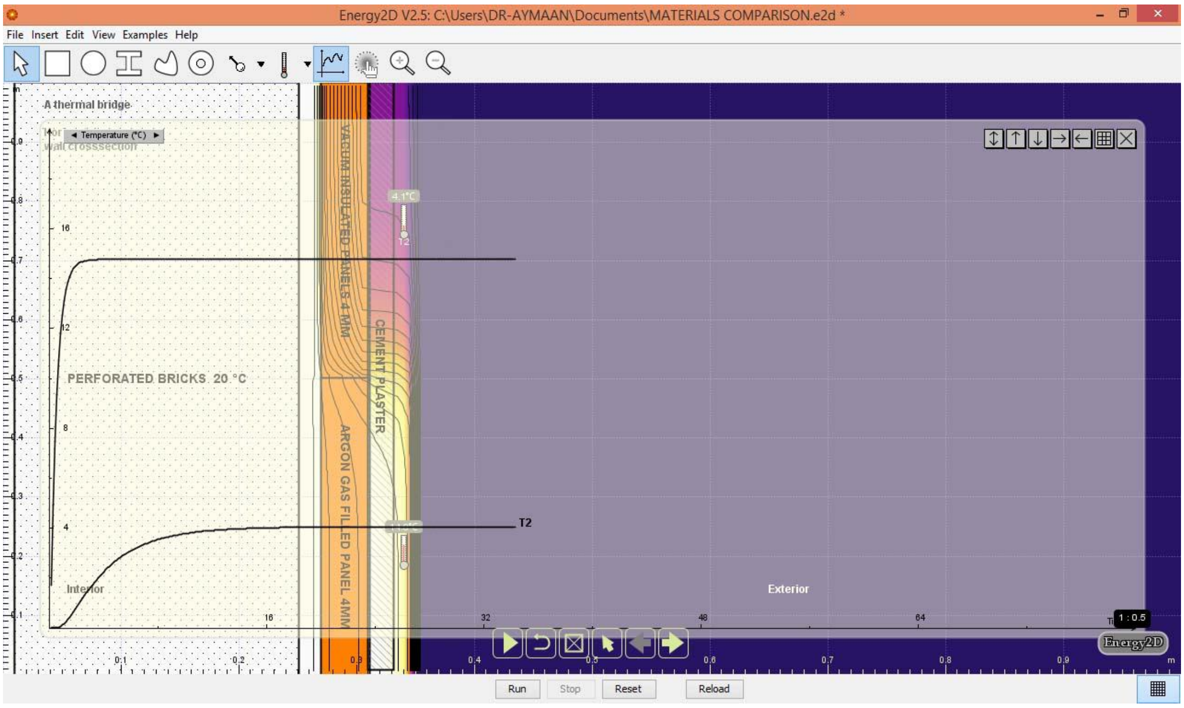


Figure 13: Horizontal cross section of two insulating materials; Vaccum Insulated Panels and Argon Gas Filled Panels for heat transfer comparison.

Figure13 presents horizontal cross section of Vaccum Insulated Panels and Argon Gas Filled Panels for the heat transfer comparison for 1 minute time interval. The results of the comparison are shown in Table 6.

Table 6: Heat transfer comparison results for Vaccum Insulated Panels and Argon Gas filled panel.

Material	**Thickness mm**	**U Value W/(M °C)**	**Outside Surface Temp after 1 minute**
Vacuum Insulated Panels	4	0.01	4°C
Argon Gas Filled Panels	4	0.04	11°C
Thermal conductivity values are those of the C4 National Building Code Of Finland – Thermal Insulation Guidelines 2002			

The results obtained in Table 6 show that the Nano-based Vaccum Insulated Panels has the lowest thermal conductivity of U Value of 0.01 W/(M °C) for a thickness of 4 mm. For the same thickness the Argon Gas Filled Panels had a U Value of 0.04 W/(M °C). Nano-based Vacuum Insulation Panels of thickness 4 mm transmit less heat for an equivalent 4 mm Argon Gas Filled Panels.

The three comparisons results show that the rate of heat transfer for external walls covered by conventional thermal insulating materials such as extruded polystyrene, glass wool, rockwool and fiberglass is higher than the state of art Nano-based thermal insulation materials.

It is worth noting that for the Egyptian construction market, the construction application of Nano-based thermal insulation materials faces some challenges such as its rare presence due to lack of local production which means a high product cost; lack of information for both the consultants and the contractors about Nano-based thermal insulation materials benefits and methods of application; and also the client environmental fear for using Nanoparticle materials.

This research concludes that in order to enhance the applicability of Nano-thermal insulation materials in the construction field in Egypt; first, information about its benefits and its assembly methods should reach the consultants and the contractors through advertising and continuous education engineering programs; second, local production of materials will lower its cost; and finally, raising the awareness of the construction expertize and professionals as well as the public about the environmental safety of Nano-materials.

4. CONCLUSION

Although Nano-technology is making a great development in the field of improving properties of conventional materials, yet there are some issues that prevent its widespread such as the unknown environmental impact of Nano-scale particle material due to the difficulty concerning checking its full life cycle assessment.

Applying Nanotechnology research to improve the thermal insulating materials properties is a vital aspect of utilizing the latest technologies to serve the global energy saving demands. This aims to produce thermal insulation materials that are lighter and thinner than conventional thermal insulating materials thus saving space. In this paper a model comparison between different insulating materials were performed. It was proved that Nano-based thermal insulating materials gave promising results when compared to conventional insulating materials. The study showed that Nano-based materials such as Vaccum Insulated Panels and Nano-based Aerogel had lower heat transfer rate at less layer thickness.

Implementation of the NBITM in the Egyptian construction market can be encouraged by facing several challenges such as producing NBTIM materials locally to lower its cost;

moreover, by increasing the knowledge about uses, benefits, and environmental safety of the NBTIM to the construction professionals as well as the public.

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