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CLIMATE ACTION AND SDGS' ATTAINMENT: INSULATION MATERIALS' IMPACTS ASSESSMENT

Abstract
Thermal insulation materials (TIM) lack of studies regarding their various impacts. Embodied energy and CO_2 associated with materials and construction throughout the whole building lifecycle account for 11% of global CO_2 emissions and the rest 28% are from buildings operation. This paper presents a study on impacts affecting conventional insulation materials (environmental, health, embodied energy and cost) in order to determine the best commonly used TIM. The objective focuses on examining the impacts of commonly used thermal insulation materials in order to define the best material with the least harmful impacts. The methodology depends on a qualitative approach that examines major impacts of conventional TIM. Results show the potential of the assessments in determining the best insulation materials and least effective to be utilized in buildings in terms of associated impacts. The results are limited to certain TIM; represented in five materials due to their importance and usage.

Keywords: *climate change adaptation, thermal insulation materials, types, impacts, SDGs.*

1. Introduction

Climate change is manifested in many countries worldwide. In year 2019 and 2018, many parts of Europe experienced severe events such as floods and heat waves that were translated in a breaking record of high temperature in Belgium, Germany, The Netherlands, and The United Kingdom. Paris was also hit by all-time breaking temperature record of 43 degree Celsius for decades [1].
According to the United Nations Environmental Program (UNEP) Status Report 2018, published by the UN Environment and the International Energy Agency (IEA), it stated that buildings and construction together account for 36 per cent of global final energy use, and 39 per cent of energy-related carbon dioxide (CO_2) of the global CO_2 emission [2].
It also indicated that the energy intensity per square meter of the global buildings sector needs to be improved on average by 30 per cent by 2030 (compared to 2015) to be on track to meet global climate ambitions set out in the Paris Agreement [2].
The IEA pointed out that the built environment including buildings in MENA region account for more than 50 per cent of the total energy consumption [3, 4]. Hence, the efficiency of the buildings' envelope, especially in the MENA region do not comply with high standards to reduce energy use [3].
The World Green Building Council (World-GBC) stated in 2019 that the building and construction sector can reach 100 per cent net-zero carbon emissions by 2050 [5].The World-GBC has also issued a bold new vision for how buildings and infrastructure around the world can reach 40 per cent less embodied carbon emissions by 2030 [5].
The Intergovernmental Panel on Climate Change (IPCC) has overlooked in the past year by research to reach a drastic cut of embodied carbon emissions in all carbon emissions over the next decade. This is a significant step in keeping global temperature rise to 1.50 degree Celsius according to Paris signed Agreement 2015 [6].
Cities have demonstrated new innovations and methods in reaching fossil energy free construction sites such as Oslo in Norway. Vancouver, Canada has also enacted polices and laws to mitigate embodied carbon in new buildings by 40 per cent by 2030 [5].
One of the most beneficial techniques to lessen the transition rate of energy consumption is the usage of thermal insulation materials to reduce heat gain or heat loss in or from buildings.
Thermal insulation materials use more carbon intensive depending on the type of materials, e.g., Polystyrene insulation is more carbon intensive than mineral wool.
Carbon emissions from insulation materials account for 11 per cent of the total CO_2 emissions, including the mineral wool, XPS (Expanded polystyrene) and EPS (Extruded polystyrene). For the most insulated case, the insulation materials are responsible for 19 per cent of the total embodied greenhouse gas (GHG) emissions of the buildings' construction sector [7].
The thermal insulation materials are not heavily used in many parts of the developing countries; therefore, it is clear that the urge to enhance the energy behavior of buildings oblige policy and decision maker, designers and local governments as well as contractors to utilize thermal insulation materials with high physical standards and diverse forms.
According to IEA, Two-thirds of countries lacked mandatory building energy codes in 2018, meaning that more than 3 billion square meters were built last years without mandatory performance requirements [8].
In order to attain sustainable development Strategy (SDS) by 2030, all nations should move towards mandatory building energy codes and high-performance new construction to increase from 250 million to 4 billion square meters, and deep energy efficiency renovation of existing building that require to double the energy intensity improvement to be at least a 30 per cent to 50 per cent [8].
In most of developing countries in recent years, there are almost no substantial studies regarding the different impacts of the building sector regarding conventional insulation materials that result in enormous impacts to be put into consideration. These impacts should be studied and highlighted based on their complexity in order to lessen these effects.
To decide on one insulating material rather than the other, putting into consideration the different aspects of each material, it is vital to give weight to each material.
Thermal insulation materials have many impacts, whether environmental, health, and air pollution, social as well as economic and cost impacts.
In this paper, the environmental, health, energy and cost impacts are highlighted, examined, and discussed. This paper presents a study conducted on the main impacts affecting the thermal insulation materials in order to determine the best commonly used conventional insulation materials in terms of various impacts.

2. Objectives

The objectives of this work are mainly to assess the various impacts of commonly used thermal insulation materials that are specifically utilized regionally in the MENA region, and to define different parameters in attempt to reach the best material with the least harmful impacts to be utilized in construction.
However, the main goal of this paper is to examine in depth the impacts of thermal insulation materials, which are classified into four fundamental impacts; including environmental, health, and embodied energy as well as cost.
The study is also concerned with the analysis of these impacts to identify the weight of each one, in an attempt to reach the best material, with the least harmful impacts.
Nevertheless, the objectives of the study can be summarized as follows and as shown in Figure 1:

a) Assessing and examining different impacts thermal insulation materials in terms of the least harmful impacts.
b) Examine the various impacts of thermal insulation materials:
   - Environmental impacts,
   - Health impacts,
   - Embodied energy impacts, and
   - Cost impacts.

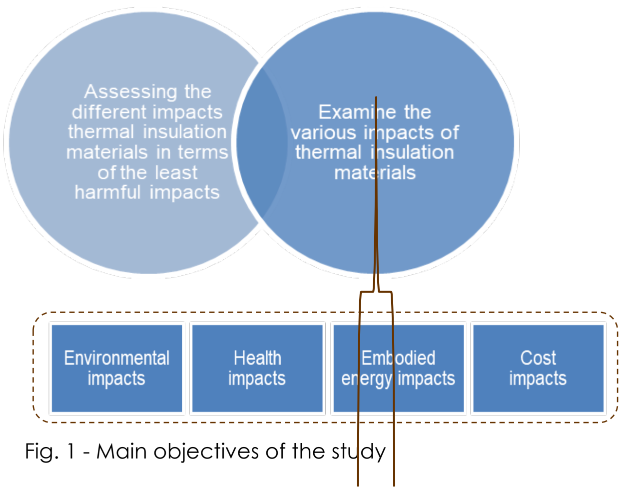

Fig. 1 - Main objectives of the study

3. Methodology

In order to examine in depth the different impacts regarding thermal insulation materials, a methodology is developed based on analytical approach utilizing a qualitative assessment to identify the weight of each impact by considering their different parameters, including their effects on: a) human health; b) generated harmful gases on the environment; c) embodied energy that is manifested in the energy consumed by all of the processes linked with the production of a building that result in CO_2 emissions that are responsible for climate change; and d) high cost or low cost.
The studied impacts are classified into four main categories: environmental impact, health impact, embodied energy impact and cost impact as shown in Figure 2. It is imperative to state that the above four categories have been selected due to their high significance and influence based on a literature review. In this method, the weight of each impact has been considered from 1 to 5 (5 indicates the highest impact and 1 is the least impact).

4. Impact of Thermal Insulation Materials

4.1. Environmental Impact

Although thermal insulation materials are known for their remarkable reduction in the operational energy of buildings and assist in reducing g heat gain in summer months or heat loss in winter months, it is clear that they are associated with a lot of chemicals that negatively affect the environment [9], hence, it is essential to classify some important thermal insulation materials prior to analyse them in terms of environmental impact due to their chemical contents. A detailed classification is carried out for the widely used insulation materials in building and market, where they can be classified according to their chemical and gaseous content. These are classified into three main categories: inorganic, organic and combined materials as shown in Figure 3. However, it is clear that not all of these materials are frequently used; where all materials, other than inorganic fibrous materials and organic foams, obviously cover only a small percentage of the market. Thermal insulation materials classification is presented in details in Figure 4 [10]:

- **Inorganic materials**: consist of basic materials and different types of rocks, with the addition of small quantities of adhesive materials or chemicals.
- **Organic materials**: consist of varying percentages of gases and chemicals, as air, carbon dioxide and pentane.
- **Combined materials**: Wood fibers and magnetite or white cement are used in the production of wood wool, along with adhesive elements.

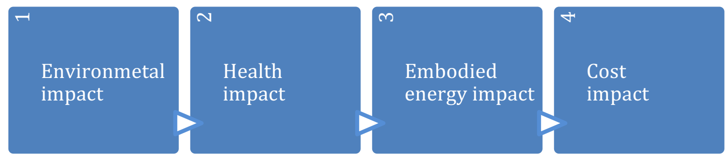

Fig. 2 - Various impacts of thermal insulation materials

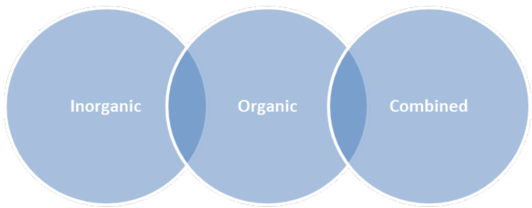

Fig. 3 - The three types of thermal insulation materials

As far as the environmental impacts of thermal insulation materials are concerned; it is clear from the evaluation that they differ from one material to another based on their chemical and gaseous contents. According to a recent report issued by the U.S. Department of Interior, environmental impacts are stated as follows [11]:

- The use of chlorofluorocarbons (CFCs) as foaming agents to increase the thermal efficiency of insulation materials, which directly results in stratospheric ozone layer depletion. By 1993, all CFCs had been substantially eliminated from insulation manufacture, and substituted hydrochlorofluorocarbons (HCFCs) in most products,
- HCFCs still result in some ozone depletion, contribute to global warming and reduce conductivity,
- Pentane is a chemical used in the formation of insulation materials, which has no impact on the ozone layer; however it has been involved in increasing smog formation, and it has also ground-level ozone pollution potential,
- Air pollution, water pollution, and erosion from mining of minerals (for example, diabase rock used in rock wool "stone wool", sand and limestone used in fiberglass) are considered from the environmental impacts of raw material acquisition.

As a matter of fact, environmental impacts of commonly used insulation materials can be summarized and illustrated in Figure 5. This summary of the insulation materials is based on their types due to chemical and gaseous contents. Based on analysing the environmental impact of different thermal insulation materials and extensive literature reviews regarding this issue, Table 1 is developed to measure the impact degree of the most commonly used materials; where it sums up the results after analysis, demonstrating that inorganic fiber materials represented in glass and stone wool, both have the lowest impact, followed by expanded and EPS, leaving polyurethane with the highest impact [12].

4.2. Health Impact

Although environmental issues vary from indoor air quality issues, yet they are closely related and insulation materials' health impacts should be taken into consideration for their environmental impacts [13]. Due to the fact that thermal insulation materials are highly effective elements in decreasing any building's used energy, and since individuals inhabit these buildings, public health plays a growing role in the quest for optimum insulation materials and the industry established goals for future developments [14]. Hence, health impact of these insulation materials during their use phase must be known. According to Kienzlen, the health risks created by thermal insulation materials must be investigated. He elaborates this concept by demonstrating that materials which emit fibers or dust must be installed in a technique that seals them from the room [15]. Duijve also agrees with this concept explaining that insulation materials cannot be accountable for the poor indoor quality compared to other materials used inside homes; but not limited to furniture, textiles and paints. He supports his opinion by stating that thermal insulation materials are almost totally derived by many researches, Table 2 consequently derived; as an assumption to measure the impact level of the most commonly used materials; displaying that inorganic fiber materials represented in glass and stone wool, both have the lowest effect environmentally, followed by XPS and EPS, in addition to polyurethane with the same degree of impact; which is considered a high one shut-in from contact with indoor air [16].
Consequently, an inspection of thermal insulation materials' health impacts (Figure 6), in an attempt to gather all possible information about these types of health impacts.

4.3. Embodied Energy Impact

Embodied energy (EmEn) is one of the most influential impacts of thermal insulation materials. A certain awareness of the EmEn and the environmental impacts of building materials could encourage the use of not only the production and development of more sustainable materials, but also their preference among construction design and industry.
Embodied energy is defined as: 'The energy consumed by all of the processes linked with the production of a building, beginning with the mining and processing of natural resources till their manufacturing phase, transport and product delivery', whereas, a substantial refinement in the efficient lifecycle energy use of buildings can be realized by reducing EmEn in building materials.

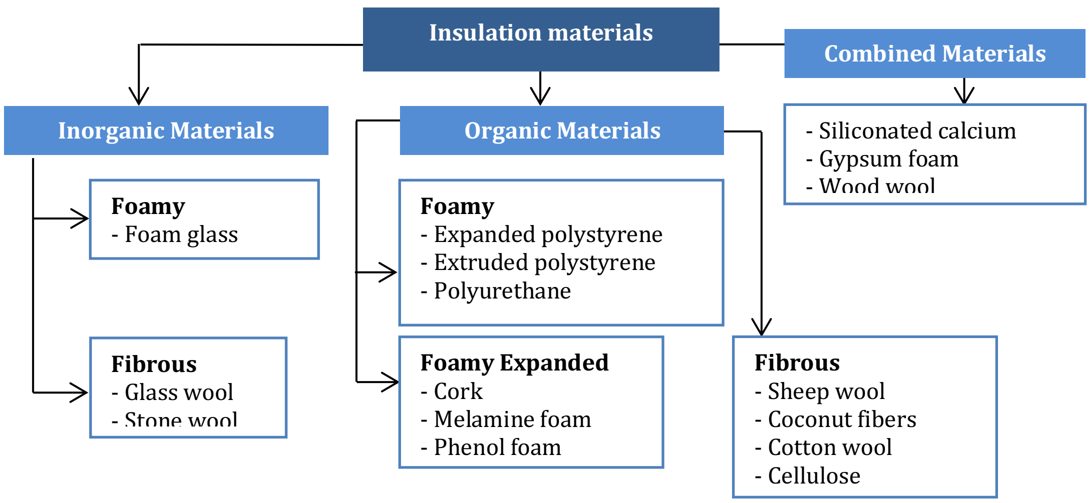

Fig. 4 - Classification of the commonly used insulation materials
Source: Papadopoulous 2002

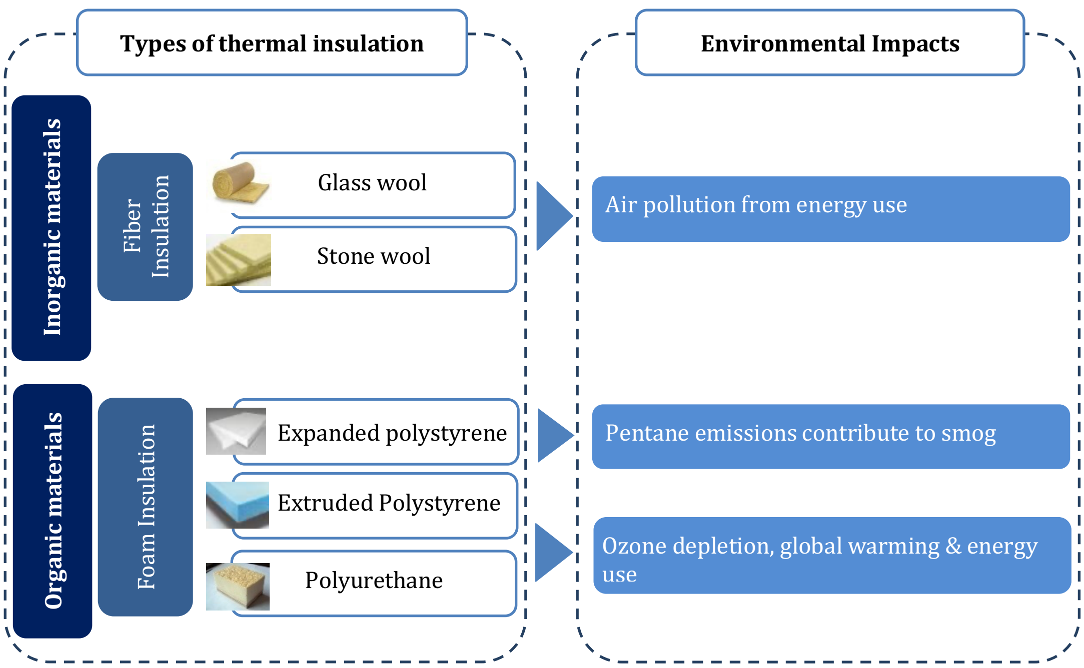

Fig. 5 - Environmental impact of thermal insulation materials types
Source: www.civil.uwaterloo.ca

Tab. 1 - Environmental impact ranking of conventional thermal insulation materials

Insulation Materials		Environmental Impact
Organic foam materials	Expanded Polystyrene	4
	Extruded Polystyrene	4
	Polyurethane	5
Inorganic fiber materials	Glass Wool	2
	Stone (rock wool)	2

Sattar takes it further by setting some principles, through which EmEn can be reduced [17], as presented in Figure 7. The main function of the insulation material is to save energy.
Most of insulation types will save more energy across their lifetime than the required energy for their manufacture. Hence, EmEn can be used as a strong differentiator between materials [9].

Tab. 2 - Environmental impact ranking of conventional thermal insulation materials

Insulation Materials		Health Impact
Organic foam materials	Expanded Polystyrene	4
	Extruded Polystyrene	4
	Polyurethane	4
Inorganic fiber materials	Glass Wool	2
	Stone (rock wool)	2

A. M. Papadopoulos strongly agrees with this fact, adding that EmEn is substantial for the choice of the material; where, a material with a lower EmEn is considered more energy efficient during the building valuable life-time [10].
Two approaches are very important for the utilization when assessing EmEn. These are: a) cradle to grave, and b) cradle to gate [17].
Figure 8 illustrates these approaches.

To Sum up, EmEn can be analysed in details by chasing an endless trail of energy calculations that can be performed to analyze any point in the processing and manufacturing chain. Putting this in mind, it is sufficient to remember the purpose of EmEn calculations; so as to make informed decisions that lead to improvements in the way we use energy [19]. Table 3 shows the EmEn along with the global warming potential of conventional insulation materials, using cradle to gate approach. Also, Figures 9 and 10 are related respectively to EmEn and global warming potential of conventional insulation materials using the same approach; where they can be used to analyse and compare these insulation materials according to EmEn and global warming potential figures (Table 3). The analysis results demonstrate that the worst performance insulating material, within the studied ones with respect to EmEn and global warming potential among the materials analysed using the cradle to gate approach, were respectively expanded and EPS, whereas the best one is stone wool. According to prior exploration of EmEn impacts of different thermal insulation materials and their and global warming graphs, Table 4 is generated for the most commonly used materials, showing that inorganic fiber materials represented in stone wool has the lowest EmEn impact, while, glass wool has a medium one. When it comes to organic foam materials, both XPS and EPS have critical EmEn impacts.

4.4. Cost Impact

Since energy prices are in continuous rise due to lifting of the energy subsidies which started in year 2014, manufacturers and buildings' users started considering thermal insulation materials as a solution to their rising energy use and electricity bills. Posterior to the clarification of EmEn impact of thermal insulation materials; the cost impact of conventional insulation materials is discussed to supplement the formerly mentioned impacts. To be clearer, the purchase and installation costs of thermal insulation materials should be considered by consumers, against the thermal efficiency required for the building. To be more precise, a higher thermal performance could be purchased and installed at a higher cost, although it is not required for the intended purpose of the building, taking into account its location and climate. However, thermal insulation material should be selected by the designer based upon the material with the lowest appropriate thermal conductivity and the highest thickness that the owner can afford [9].
The costs for different types of conventional insulation materials are quoted based on the most used thermal insulation materials and the average costs of local insulation companies in Egypt. In fact, these costs were obtained through personal interviews with some of these companies. The costs are indicative and dependent on the market inconstancy and the local conditions at the time of investigation based on values of October 2019. These costs are the average ones for squared meter, arranged in a descending order from the highest cost to the lowest one, according to local vendors in Egypt as follows:

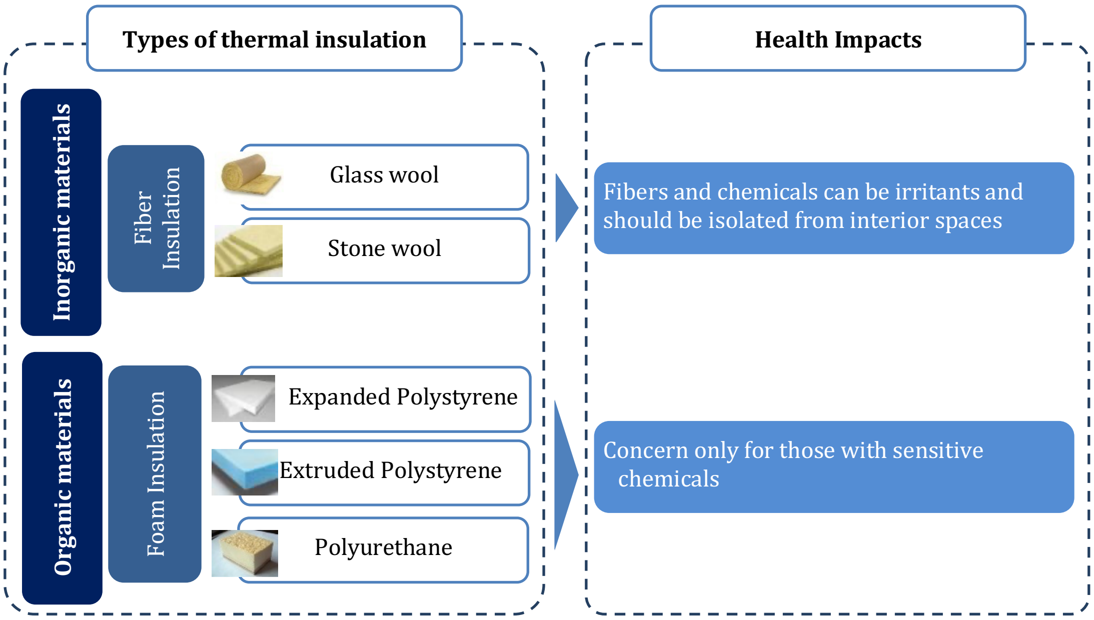

Fig. 6 - Health impact of thermal insulation materials types
Source: www.civil.uwaterloo.ca

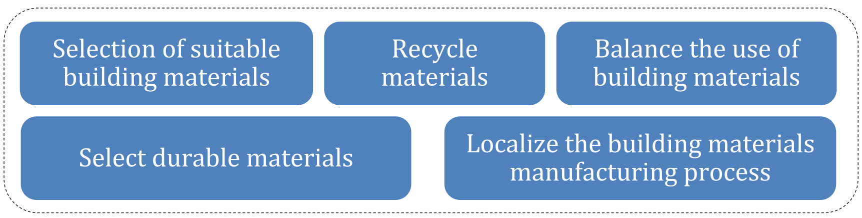

Fig. 7 - Embodied energy reduction principles
Source: Sattar 2012

Tab. 3: Embodied energy and global warming potential of conventional thermal insulation materials
Source: European Commission report 2010

Material	Energy consumption (embodied energy, MJ per kg)	Global warming potential (kg CO_2 per kg)	Approach
Expanded Polystyrene	88.6	2.5	Cradle to gate
Extruded Polystyrene	88.6	Around 2.5	
Polyurethane	72.1	3	
Glass Wool	28	1.35	
Stone (rock wool)	16.6	1.2	

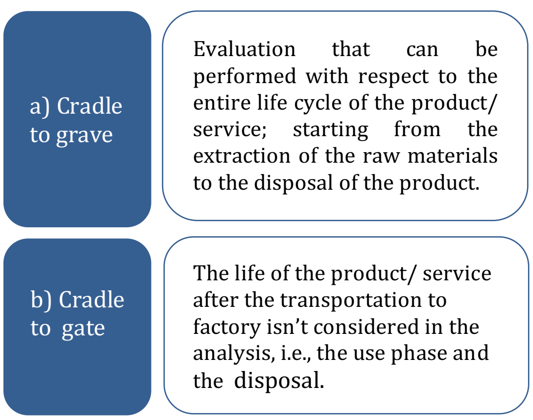

Fig. 8 - Approaches of Embodied Energy
Source: S. Schiavoni 2016

- Target, International company for rock wool "Rockal", and
- Sodeco EG, and Chemicals for Modern Building "CMB".

Average local costs for a squared meter of thermal insulation material: a) Stone "Rock wool": 380 EGP (€ 21.23); b) Glass wool: 350 EGP (€ 21.23); c) Expanded Polystyrene: 290 EGP (€ 16.20); d) Extruded Polystyrene: 260 EGP (€ 14.53), and e) Polyurethane: 58 EGP (€ 3.42). Although Polyurethane is believed to have the lowest cost among the other insulation materials, it has the highest global warming (GW) potential (3.0 $KgCO_2/Kg$) and considered to have higher EmEn (72.1MJ/Kg) in manufacture. Glass wool possesses a high price, except the fact that it also happens to have low EmEn and GW potential respectively (28MJ/Kg and 1.35 $KgCO_2/Kg$). As a matter of fact, XPS and EPS are believed to have reasonable prices, where they are also considered from the large contributors to global warming potential with high EmEn, wherease Stone (rock) wool turned out to have the highest price of all the thermal insulation materials. Yet, it has the lowest EmEn and GW potential respectively (16.6MJ/Kg and 1.2 $KgCO_2/Kg$). After the manifestation of the most commonly used thermal insulation materials cost according to Egypt's local market, Table 5 is deduced and developed. It shows that polyurethane represents the organic foam materials happen to have the lowest cost impact, whereas, inorganic fiber materials represented in glass wool has low environmental and health impact, but it has an extremely high cost impact.

5. Results and Discussions

The assessment of four category of thermal insulation materials' impacts, based on selected parameters are shown in Figures 6–10. The ranking of the impacts according to their weight are also shown in Table 1 to 4. Table 6 summarizes the best insulation materials in relation to the least effective ones, highlighting the best with light blue color due to low impact, and the weakest reaches dark blue color due to the extremely high impact, based on the previously mentioned impacts affecting these materials.

By comparing the four impacts and calculate the average of the total impact, it shows that rock wool has the least impact among all the studied conventional thermal insulation materials, which is 2.5; whereas the highest impact of the conventional materials, are 3.75, 3.75, and 4 for the XPS, EPS, and Polyurethane respectively. Concerning the environmental impact, polystyrene has the highest weight (5), followed by XPS and EPS, whereas the lowest weight is rock wool (2). For the health impact, the first three insulation materials have the highest impact with the following weight (XPS (4), EPS (4), and Polyurethane (4). Regarding EmEn impact, the EPS and XPS have the highest weight (each 5), followed by Polyurethane and Glass wool with weight of 4 and 3 respectively, whereas the lowest weight is rock wool (1). Concerning the cost impact, glass wool and Rock wool have the highest weight (5), followed by XPS and EPS with weight 3, whereas the lowest weight is polyurethane (2).

6. Conclusions

The varying impacts of the conventional thermal insulation materials are unfortunately not studied in a wide range, although they play a major role in deciding on the most convenient materials. The study on the main impacts affecting the thermal insulation materials in order to determine the best commonly used conventional insulation materials in terms of various impacts has been carried out. Thermal insulation materials impacts, whether environmental, health, air pollution, energy or cost and economic have been addressed. The environmental, health, EmEn and cost impacts were highlighted, examined, and discussed. Different impacts of commonly used thermal insulation materials in order to define different parameters, in an attempt to reach the best material with the least harmful impacts to be utilized in construction were examined. The environmental impact encompases insulation materials classification and due to gases and chemicals contents. For the EmEn; it is estimated due to two main approaches; that are cradle to gate and cradle to grave approach. The worse conventional thermal insulation materials in terms of their impacts are XPS and EPS respectively. In contrast, stone wool followed by glass wool proved to be the best materials. Considering the cost impact of thermal insulation materials; based on the optimum insulation thickness for each climatic zone proved to be a major influencer that helps in deciding on the minimal total cost for the building. Using the qualitative approach, it proved to be indicative and significant in determining the best and the least thermal

Tab. 4 - Embodied Energy ranking of conventional thermal insulation materials

Insulation Materials		Embodied Energy Impact
Organic foam materials	Expanded Polystyrene	5
	Extruded Polystyrene	5
	Polyurethane	4
Inorganic fiber materials	Glass Wool	3
	Stone (rock wool)	1

Tab. 5 - Cost Impact ranking of conventional thermal insulation materials

Insulation Materials		Cost Impact
Organic foam materials	Expanded Polystyrene	3
	Extruded Polystyrene	3
	Polyurethane	2
Inorganic fiber materials	Glass Wool	4
	Stone (rock wool)	5

Tab. 6 - Comparison between conventional thermal insulation materials different impacts

Insulation Materials		Environmental Impact	Health Impact	Embodied Energy	Cost Impact	Average Impact
Conventional	Expanded Polystyrene	4	4	5	3	3.75
	Extruded Polystyrene	4	4	5	3	3.75
	Polyurethane	5	4	4	2	4
	Glass Wool	2	2	3	5	3
	Stone (rock wool)	2	2	1	5	2.5

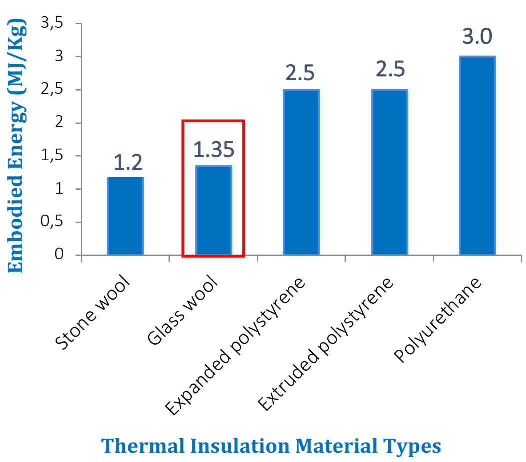

Fig. 9 - Embodied Energy of conventional thermal insulation materials
(Cradle to gate approach)
Source: Authors after European Commission (EC) Report 2010

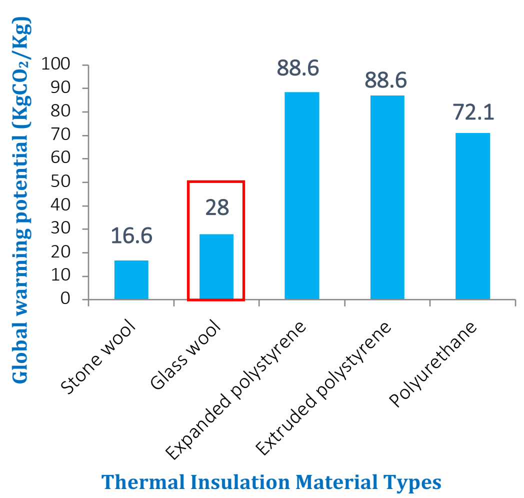

Fig. 10 - Global Warming potential of conventional thermal insulation materials
(Cradle to gate approach)
Source: Authors after European Commission (EC) Report 2010

insulation material is dividing the estimated impact degree of the materials; whereas the analysis and literature review were useful in highlighting the number of impacts to reach an average overall impact. Based on the results regarding the impact degree of the commonly used conventional thermal insulation materials upon the analysis and investigation of their environmental, health, EmEn and cost impact, stone (rock) wool turns out to be the material with the lowest overall average impact; to be the best insulation material to be used on all levels, followed by glass wool, to leave XPS and EPS with the highest overall impacts. With the climate change manifestation in Egypt, it is important to enforce the use of thermal insulation materials that have the least impacts in all buildings as an action for climate change adaptation. This should not occur only in new building, but also to enhance the existing stock to be efficient.

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