Analysing the Impact of the Building Materials on the Energy Consumption of the Building

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Abstract. Most of the old buildings, over their service lives absorbs carbon through processes such as carbonation in concrete and absorption in timber. In comparison with the newer buildings, the older buildings have less insulation which may make them less energy efficient. This study focuses on the analysis of the impact of the material insulation on the energy performance of the building. To determine this, a floor of the building is examined in this study using Building Information Modelling. In one model, the walls were made of a material with less insulation having thermal resistance (R), heat transfer coefficient (U) and thermal mass of 4.2386 (m^2.K)/W, 0.2359 Q/ (m^2.k), and 299.48 kJ/(m^2/k), respectively. While in another model with same architectural parameters, the walls were made with material with high insulation having thermal resistance (R), heat transfer coefficient (U) and thermal mass of 5.2757 (m^2.K)/W, 0.1895 W/ (m^2.K), and 924.04 KJ/ (m^2.K), respectively. The impact of the insulation on the energy consumption of the models were analysed using Autodesk Insight. The difference in the energy performance between the low insulation material and high insulation material was 1.9 USD/m^2/yr., highlighting the importance of the insulation on the overall energy efficiency of the building.

Keywords: building, insulation, energy efficient, energy performance, thermal resistance, heat transfer coefficient, thermal mass.

1 Introduction

The building sector alone is accountable 39% of the greenhouse gas emissions (GHGe) [1], [2]. These emissions include embodied carbon and operational carbon. The embodied carbon is the carbon that is induced in the building materials. Over the time, the carbon is diffused into the building insulation materials and effects the overall building performance. Over the recent years, European Commission and its member states have introduced strict energy efficiency regulations for the new constructions and for the retrofitting of the old buildings. As the population is expanding, therefore it is expected that there will be surge increase in the housing crises which will amount for more construction related projects [3].

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In the general point of view, the energy consumption is comprised of three parts namely: construction, employment and demolition. In the recent studies, the researchers have studied the effect of the insulation thickness on the overall energy performance of the building [4], [5], [6]. The amount of optimal insulation thickness is also dependent on the accurate measurement of the Heating, Ventilation, and Air Conditioning (HVAC) loads [7]. The location of the insulation in the wall plays a significant role in the overall building efficiency. For example: the exterior walls will be more influenced by the outside temperature than the interior walls. Likely, the exterior walls have more chance of inducing carbon than the interior walls. Bojic´and Loveday in their study employed BRE-ADMIT[8] to assess the insulation distribution in a construction and found that by improving the construction of specific areas can improve the energy efficiency of the building by 32% to 72%. Whereas Asan in his study assessed six walls and found out that the insulation has profound effect on the decrement factor and maximum time lag [9].

In addition to the climatic condition in which the building is located, is significant in analysing the load that the HVAC systems will bear to moderate the room temperature. This will be significant in South Asian countries than Europe. While in Europe, the buildings endure wetting rain seasons throughout the year. These all parameters are useful while performing building retrofitting, due to which software like Building Information Modelling have gained popularity in assessing the building lifecycle. It is worth noting that the BIM is increasing applied in combination with the energy modelling as it serves as a knowledge base for providing the needed inputs. The potential of BIM has been highlighted in several studies in which it is suggested that the BIM should be applied from the initial stage of the project, and it can be useful in assisting the environmental factors of the construction/building, however the solid framework on implementation of BIM is lacking [10], [11], [12], [13].

BIM, which is powerful tool, requires high level expertise when it comes to making building models due to level of details included in it. The potential BIM is explored in this study, when comparing the low insulation material used for the exterior wall of the building with the high insulation material using the Autodesk Insight. This study is significant in developing an understanding of the influence that a building material can have in impacting the overall building energy efficiency.

2 Key Terminology in Building Insulation

To understand the properties of the construction materials used in building insulation, it is essential to understand its fundamental terminologies, which includes heat transfer co-efficient, thermal resistance, and thermal mass. Each of them has a significant role in maintaining the building energy efficiency by determining the effectiveness of the insulation.

2.1 Heat Transfer Coefficient

The heat transfer coefficient represents the measure of heat flow through a material. It is denoted by U and its unit is watts per square meter per degree Kelvin ($W/m^2.K$). A lower heat transfer indicates that the material has a good insulation capacity whereas a high heat transfer indicates the low insulation capability of the material [14], [15]. It is a critical parameter of material insulation which directly influences the amount of energy required to cool or warm a building. Effective insulation materials have low heat transfer coefficient which means that material will keep the building warm in the winter and cooler in the summer.

2.2 Thermal Resistance

Thermal resistance is the capability of a material to resist the heat flow. It is denoted by R and it is expressed in units of square meters Kelvin per watt ($(m^2.K)/W$). A higher resistance value represents the better insulation capability as the material is resisting the flow of heat [16], [17]. In terms of building construction, the usage of materials with higher thermal resistance indicates that the building walls, roof, floors, doors and windows will be better at keeping the indoor temperature stable without a need of additional heating and cooling.

2.3 Thermal Mass

Thermal mass is the capacity of a material to absorb, store and later release the heat. It is measured in kilojoules per square meters Kelvin per watt ($(m^2.K)/W$). Materials like concrete and brick that are having high thermal mass absorb the heat during the day and later release it during the at night when the temperature drops. This ability of the materials helps the building to maintain its temperature and enhances the overall building energy efficiency. Materials with high thermal mass can reduce the reliance on heating and cooling systems leading to lower energy consumption and costs [18], [19].

3 Developing the Building Information Model

For this study, the second floor of an institutional building was selected, having a floor area of approximately 2900 m^2. The building is a hub to research and development and have been in usage since long. The building's data like its architectural designs and building envelope was provided by the building manager. Building Information Modelling on the architectural design of the second floor of an institutional building was performed using Autodesk Revit.

Using Revit, two models were developed having the exterior walls with different insulation properties as illustrated in the figure 1.

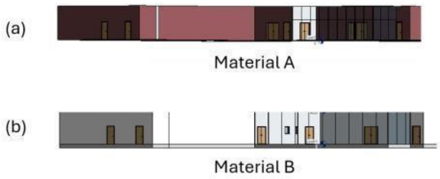

Fig. 1. Building floor with same dimensions constructed with two different materials

The properties of the material that were used in this study are:

Table 1. Properties of the building materials

Property	Material A	Material B
Heat Transfer Coefficient	0.2359 W/ (m^2.k)	0.1895 W/ (m^2.K)
Thermal Resistance	4.2386 (m^2.K)/W	5.2757 (m^2.K)/W
Thermal Mass	299.480010 kJ/(m^2/k)	924.039000 KJ/ (m^2.K)

To understand the climatic change of the environment on the structure, the location of the building was selected which was in Dublin, Ireland as illustrated in the figure 2.

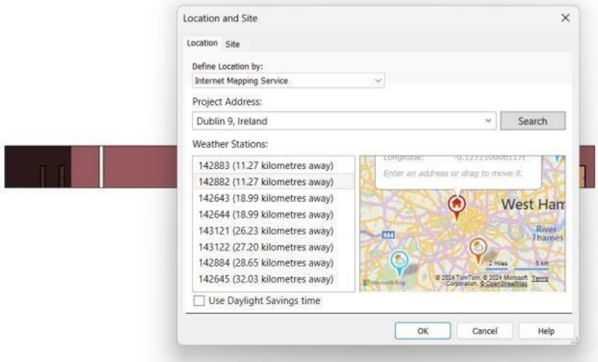

Fig. 2. Geolocation of the building

After providing the building dimensions and having the same physical properties of the interior walls, floor, doors and windows, the energy model of the structure was created using the Autodesk Insight. The findings from the energy model are shown in figure 3.

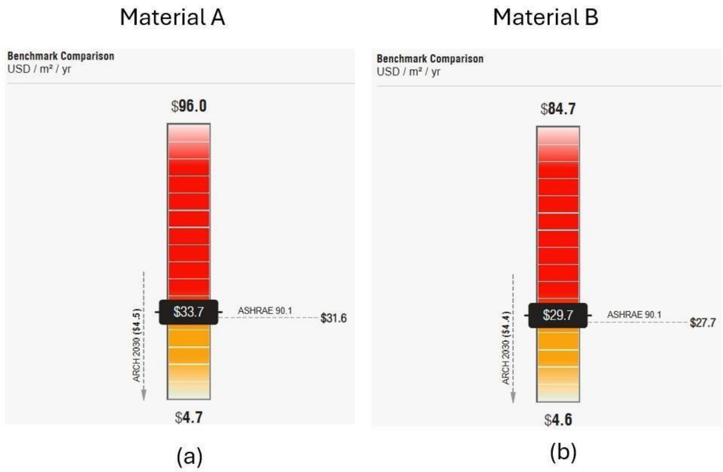

Fig. 3. Energy Consumption

According to the benchmark comparison of the energy consumed by the second floor of the building having Material A and Material B are $33.7 USD/m2/yr. and $29.7 USD/m2/yr. The second floor constructed using Material B consumes less energy in comparison to the second floor constructed using Material A.

4 Conclusions

While comparing the characteristics of the Material A and Material B, that are having same dimensions but different insulation properties. The major difference between the materials is their thermal mass. The thermal mass of Material A is 299.480010 kJ/(m^2/k) whereas the thermal mass of Material B is 924.039000 KJ/ (m^2.K), which is more than thrice of the thermal mass of the Material B. That indicates that the Material B has more capacity of absorption, storage and release of the heat which makes it a suitable choice for insulation.

While comparing the insulation properties of the exterior walls, the electricity consumption of the building having material A and material B are $33.7 USD/m2/yr. and $29.7 USD/m2/yr. These results indicate an inverse relationship between the thermal mass of the material used in the building and the annual electricity consumption of the building.

As the building floor is of 2900 m^2, the annual building's energy consumption will be:

Table 2. Annual building's energy consumption

Floor 2	USD/m2/yr	USD/yr (Total Area: 2900 m^2)

Material A	33.7	97790
Material B	29.7	86130
Difference of $11,660		

The difference by just changing the material of the exterior wall is $11,660 (10840 Euros), which is huge. To calculate the equivalent carbon emission of 10840 Euros/yr in terms of Ireland, the following mathematical equations will be used:

$$Energy\ consumption = (Annual\ Cost)/(Cost\ per\ kWh) \quad (1)$$

Where the Cost per kWh applied for Ireland is 0.24 Euros/kWh and the carbon (CO_2) emitted per kWh is 300 g CO_2/kWh.

By employing the equation 1, the building has the energy difference of 45166.67 kWh which is 13.55 metric tons of CO_2. In can be concluded that with usage of Material B in replacement of Material A, the floor 2 of the building will have reduction of 13.55 metric tons of the CO2.

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