Environmental Optimization of Building Insulation Thickness for Cold Climates using Neural Network Method

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Abstract

In this research the environmental effects (CO_2) of rock wool as a mineral insulation and expanded polystyrene as a polymeric insulation for building insulation is studied. First the intended building is simulated by Design Builder software for cold climates like Tabriz city in Iran, and then the thickness effect of these two insulations is studied at the building's exterior wall by using Energy Plus simulation engine in Design Builder software in order to find the optimized thickness in terms of environmental effect (CO_2). Except considering the gas emission amount of building's heating and cooling systems in a year, the amount of CO_2 gas consumption in production process to installation of various thicknesses has been also taken into account. Finally by using Single Layer Perceptron Artificial Neural Network method, the environmental optimized thickness of insulation in terms of gas emission while consuming energy in building and its production during the manufacturing of insulation over ten years span in cold areas of Iran like Tabriz, is 12.5 centimeters for expanded polystyrene and 8.8 centimeters for rock wool. It is concluded that from gas emission perspective in cold climates, the mineral insulation such as rock wool is has lower optimized thickness comparing to polymeric insulation like expanded polystyrene.

Keywords: Thermal Insulation; Optimum Insulation Thickness; Environmental Analysis.

1. Introduction

More than a third of total generated energy at world level is used for heating and cooling devices. Therefore saving energy consumption in these systems has a great contribution in reducing the total energy usage [1]. Energy saving and thermal insulation issue has become a serious topic at international level and numerous efforts were made to lower the amount of energy consumption. The rising cost of fuel in recent decades has led to several developments in industries and constructions to reduce the energy usage. Due to the increase in human's need for energy, reduction of fossil fuels and rising energy prices in world, the insulation industry became a reliable and efficient solution that has drawn the attention of developed countries around the world. For this reason the last two decades are called the era of thermal insulation [2,3]. The most appropriate way for the reduction of used energy and environmental effect distribution in buildings, is insulating the building exterior walls. Although using thermal insulation results in increasing the initial expenses, thermal insulations are employed to prevent the entry and exit of coldness and heat between the inside and outside space of buildings.

This eventually leads to the reduction of energy usage and consequently decreasing the greenhouse gas emission. For this purpose the exterior walls should covered by thermal insulators [4,5]. Due to high energy consumption in buildings, it is important to reduce the fuel usage and prevent the air and environment pollution [6,7]. In EU the buildings share in the amount of energy usage and its pollution is 44 percent of the total used energy and from this 63 percent is related to residential buildings. Also residential buildings are the fourth source of greenhouse gases in EU and as a pollutant emitter, their share in the production of greenhouse gases is 14 percent. In Iran the largest energy consumer is the construction sector and its share in energy usage is 42 percent comparing to other sections. Also 25 percent of the country's natural gas is used by this section [8,9]. According to the high share of energy consumption in this sector, the precise calculation of thermal and cooling energy and its analysis is extremely important. The large energy usage of domestic sections and the importance of energy optimization in this section require fundamental decisions to reduce the energy consumption in heating, cooling and lighting systems [10,11]. Hence, the thermal insulation of buildings and using insulators with high efficiency and the ability to keep a stable building temperature in different seasons has been considered.

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The effect of external walls on the interior temperature changes due to the direct receive of thermal energy is significant and it is necessary to examine the properties of exterior walls in energy receiving and obtain the optimized pattern based on idle system. As a result, energy consumption optimization has become one of the most important issues in all energy industries the use of residential apartment complexes has increase significantly due to the shortage of land and the growing population in cities. Lack of attention to the harmony of buildings and nature to achieve a comfortable environment in cities has increase the demand for energy usage [12,13]. Fortunately, in recent years, the economic policies of governments are that the energy consumption at all sections, in addition to being optimal, has to reduce the environmental pollution of fossil fuels. As the main connection between the outside and inside space, the building's shell is the most important factor in heat loss and the study of thermal behavior and thermal performance in materials has become an important issue discussed in most countries construction regulations [14,15].

There are many factors affecting the thermal and cooling loads and energy transformation from them in buildings, which include the type of climate, building function, building's cover and the type and size of heating and cooling systems. One of the most parameters in choosing the insulation is its operation temperature range.

For each insulation, depending on their material, a specific working temperature is defined.

This means that the insulator will have its best function in this range and some insulations will lose their properties out of this working temperature [16,17].

Thermal insulations were designed and manufactured for commercial purposes at the beginning of industrial revolution and mid 19th century.

The first paper on building's thermal insulation was written by Wilson in 1959 [18]. Energy saving and thermal insulation issue has been discussed internationally since the greenhouse gas emissions crisis, and several actions were done to reduce the amount of consuming energy and environmental destruction effects of using fossil fuels.

The increase in fuel price over the past decades has led to many changes in industries and constructions to lower the energy usage, which is the reason for many activities that take place to decrease the energy consumption in different sections, including buildings [19]. In this study the effect of building walls insulation on the reduction of CO_2 as a result of building heating and cooling system's energy usage is investigated.

2. Materials and Methods

In this study, a prototype building of mehr housing plans in cold and dry climates such as Tabriz, Iran, is simulated using Design Builder software and the amount of generated environmental effects by energy consumption in building is investigated to obtain the optimum value of insulation in terms of greenhouse gas emission by the using thermal network optimization method. First with the help of drawing commands, the prototype building is plotted software's environment.

Then by applying the wall materials, openings, determining the heating and cooling systems and building function, the thermal loading of complex is calculated and various uses of energy will be modeled. The economic energy analysis method is also a life cycle cost method and for optimizing data, genetic algorithm optimization is one of the most used procedures that can be done by MATLAB software.
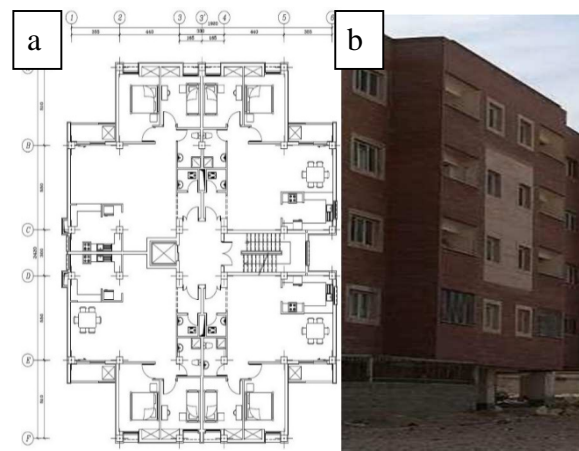
Fig. 1. a) Building floors plan. b) Building frontage[20].

Finally by changing the building heating and cooling system's size, the environmental effects (CO_2) are analyzed.

The intended building's plan is chosen from the mehr housing's constructed building in Parand, which has four floors and four units at each floor. The area of each unit is 90 square meters and total area of the land is 1442 square meters. On the ground floor, parking, storage rooms and Janitor room is provided and on each unit of the building, 4 adults are considered. The floor plan and building's frontage is shown in (Fig. 1.).

The materials for exterior walls from outside to inside respectively are: 1.5 cm granite stone, 1.5 cm mortar, 14 cm brick, reliable insulation layer and 3 cm of plaster.

Table. 1. Characteristics of the materials used in the elements of the prototype building.

	Composition		Thickness (cm)	ρ (kg/m^3)	c_p $(kj/kg.K)$	k $(W/m.K)$	U (W/m^2K)
External Wall	Plaster		2	1000	0.91	0.45	1.72 (Without insulation)
	Insulation	EPS	-	15	1.41	0.04	
		Rock Wool	-	92	0.84	0.04	
	Hollow brick		15	950	0.84	0.31	
	Mortar		2	2800	0.89	0.85	
	Stone-Granite		1.5	2880	0.84	3.49	
Floor/Ceiling	Ceramic Tile		0.5	1700	0.85	0.81	1.07
	Mortar		1.5	2800	0.89	0.83	
	Cement Block		30	1200	0.93	0.45	
	Plaster		2	1000	0.91	0.45	
Roof	Asphalt		3	2330	0.84	1.15	1.18
	Mortar		1.5	2800	0.89	0.83	
	Cement Block		30	1200	0.93	0.45	
	Plaster		3	1000	0.91	0.45	
Window	Double wall	Glass	0.6	140	0.85	0.82	3.09
		Air Space	0.6	1.21	1	0.05	

Schematic of the building exterior wall's structure is illustrated in Fig. 2.
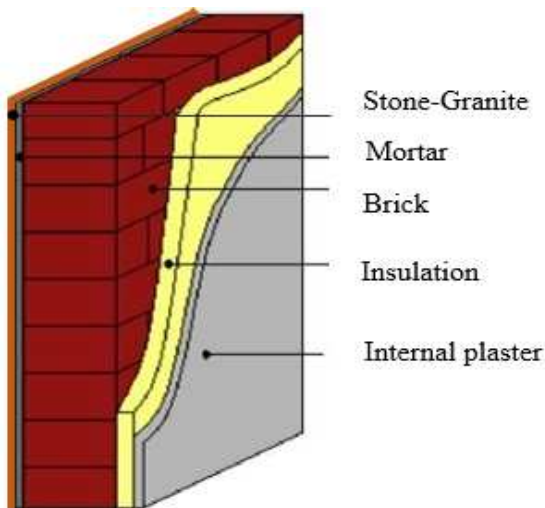
Fig. 2. Structure of the investigated extern

2.1. Climate

In this research, a cold and dry climate zone like Tabriz in Iran is considered. Fig. 3. shows the geographical location of Tabriz in Iran map.

Fig. 3. Climate zones of Iran and selected city in this study

2.2. Calculating the heating and cooling loads

The building floors are modeled in Design Builder software according to the original maps.

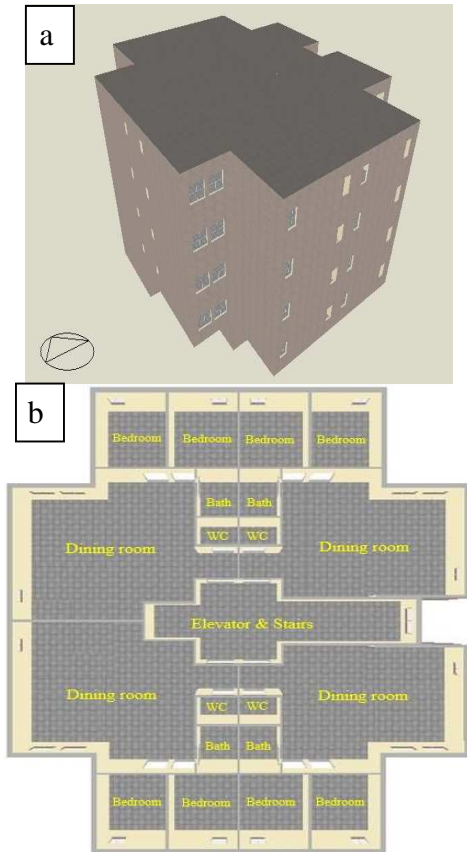The building floors and floor plans are shown in (Fig. 4.).

Fig. 4. Simulated view using Design Builder, a) The entire building, b) Type floors plan.

It can be seen that all the different parts of home including the kitchen, bathrooms, living rooms, dining room and staircase are precisely modeled by the software. Similarly all the type floors and ground floor of the prototype building is simulated in 3D by Design Builder software[20].

Today for environmental effects (CO_2) assessment, not only the amount of emitted gas due to heating or cooling is considered but the amount of produced gas at all stages from extraction to production and transformation of building materials is also investigated [21].

Finally the environmental effect (CO_2) in general is obtained from Eq (1). [21].

$$CO_{2_t} = N \times \left(CO_{2_{el}} + CO_{2_g} \right) + \left(CO_{2_0} \times M_{ins} \right) \qquad \text{Eq. (1)}$$

Where Mins is the amount of insulation material used as construction material and its thickness varies in this study. N is the time considered for calculating the environmental effect of electricity (CO_{2_el}) and gas (CO_{2_g}) consumption.

At the end of this study, the amount of (CO_{2_t}) is calculated for the optimum thickness of different insulations for Tabriz city in Kg per square meters.

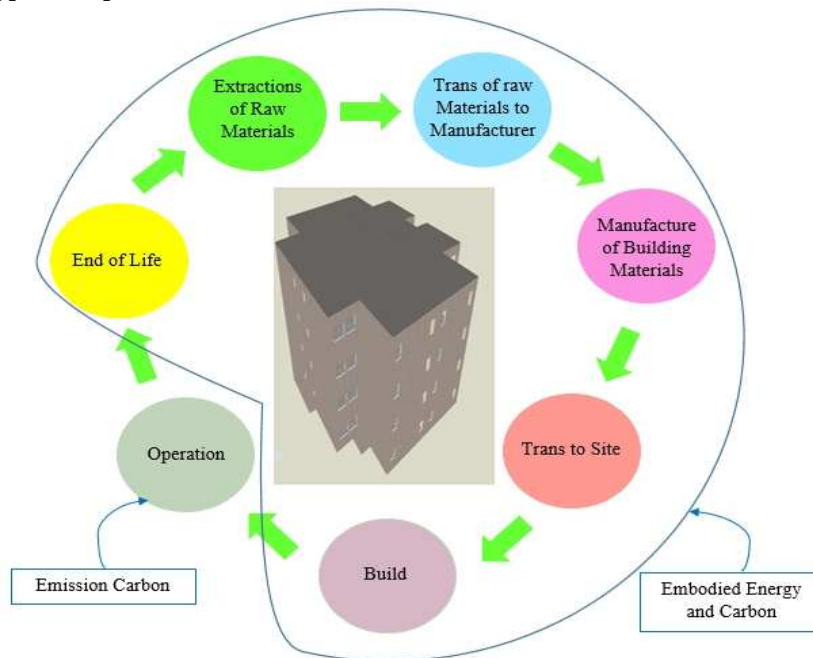All the steps related to CO_2 gas emission are shown in (Fig. 5.)[21].

Fig. 5. Illustration of different failure modes. (a, b) sample 1,2 interfacial fracture with partially button pull and partial thickness fracture, (c) sample 3, interfacial fracture with partial thickness fracture[21].

2.3. Using neural network

One of the most important capabilities of neural network is its ability to be trained. In each neural network, there are values called free parameters that can be changed. Determining the correct value of these parameters guarantees the proper performance of network in solving the aimed problem. Hence, training a multilayer perceptron neural network means that the network free parameters (weights and bias) are optimized by training algorithms and based on training data (including input and target vectors) to minimize the error between the network output and target parameter. Generally there are two types of training including supervised training and unsupervised. For neural network training with supervision, a cost function is defined and a set of experimental data are used to determine neural network weights. In this type of training, network weights are adjusted in a way that the cost function is minimized based on training data. The back propagation of error training method is a supervised and error correction law based training method used to train the feedforward neural network and is also called multilayer perceptron network. It is proved that the back propagation of error training algorithm is the most popular and best algorithm in multilayer neural networks[19,20].

3. Results and Discussion

In this study, The optimized thickness of two polymeric and mineral insulations, such as expanded polystyrene and rock wool, for cold climate like Tabriz in Iran is obtained with the help of Design Builder software and single layer neural network method. As it can be seen from fig. 6 by increasing the thickness of EPS and rock wool insulations, the amount of CO_2 emissions is reduced.
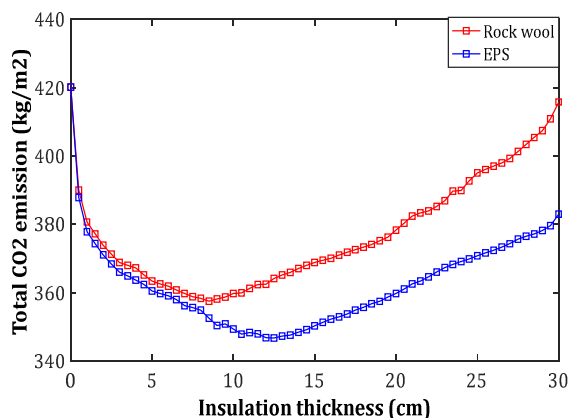

Fig. 6. The optimized environmental thickness of expanded polystyrene and rock wool in Tabriz cold climate.

From this figure the calculated overall optimum environmental thickness for expanded polystyrene insulation is 12.5 cm and for rock wool is 8.8 cm. Also the total CO_2 greenhouse gas calculated for expanded polystyrene with optimized thickness is 345 Kg per square meters and 358 Kg per square meters for rock wool insulations.

4. Conclusion

One of the best ways to reduce buildings energy consumption, overall cost and total CO_2 emissions is to limit heat loss/gain through external walls. In this study, an environmental optimum insulation thickness for a lifetime of 10 years was calculated for one selected city with Cold-dry climate in Iran which is Tabriz. As resulted:

1. Any increase in insulation thickness leads to a decrease in CO_2 emissions. But the increase in insulation thickness towards reducing energy consumptions and CO_2 emissions causes an increase in embodied CO_2 values. Hence, to determine an environmental optimum insulation thickness both embodied and emission values of CO_2 must be taken into account.

2. Expanded polystyrene which is a polymer insulation material has more harmful effects on the environment while also having a larger optimum insulation thickness so it is clear that the use of a mineral insulation material such as rock wool is more environment friendly.

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