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Investment-savings method for energy-economic optimization of external wall thermal insulation thickness

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ABSTRACT

This article analyses the optimum energy-economic thickness of thermal insulation layer for external wall. The analysis was performed by applying a new method ‘investment-savings’. An appropriate mathematical model was developed during the work. The mathematical model consists of energy and economic part. The economic part of the model contains algebraic equations for investment, exploitation and savings. The considered wall was made of brick and polystyrene was used as thermal insulation material. The heat transfer through the wall was steady-state. An analytical-numerical and graph-numerical methods were applied to solve the mathematical model. The minimum payback period of the investment was the optimization criterion. The numerical results obtained by the simulation are presented graphically. The optimum thickness of the thermal insulation layer is shown in the diagrams. In addition, by applying the developed mathematical model the optimum thickness of thermal insulation layer for energy-economic conditions in Serbia in 2014 was obtained. By applying the current prices in Serbia, the energy-economic efficient optimum thickness of the thermal insulation layer of the polystyrene is 6.89 cm which is rounded to ≈7 cm. Polystyrene can be bought in 1, 2, 3, . . ., 7, . . ., 10, . . . cm thickness only. The payback period is 1.22 years if the price of electric energy is 0.09 €/kWh. A significant result of the study: increase in thickness by 4.86 times, while investment increases only by 1.69 times.

1. Introduction

Serbia now has the lowest level of energy efficiency in Europe. It is ranked at the bottom of the list among countries using energy rationally. Buildings in Serbia are huge energy consumers. The average consumption of final energy in buildings of the European Union for thermal purposes is 138 [kWh/m^2]. In most developed countries the tendency is to reach a value below 70 [kWh/m^2]. In Serbia, it is about 200 [kWh/m^2]. Therefore, the reduction of energy consumption and improvement of energy efficiency are necessary.

In this study effectiveness is an energy-economic category. Achieving maximum results with minimal investment is a general principle of economic efficiency. It is necessary to increase efficiency and reduce costs and to reduce the harmful impact on the environment. The solution reduces the use of natural sources, generates less waste and less air pollution. In this way, the demanding task of the 3 E-formula: energy, economy, ecology can be accomplished.

Respecting the principles of energy efficiency has become a liability, not the individual’s choice. In the introduction of the Directive on the energy performance of buildings (EPBD – Energy Performance of Buildings Directive), the European Union is trying to reduce the amount of energy used in buildings.

The EPBD includes the adoption of appropriate regulations, incorporated in the legislation of Serbia. The assessment study on energy efficiency has become a legal obligation since September 2012. This means, that all houses built according to this law, when used, will consume less energy. But new buildings make up a small percentage of the total amount of constructed buildings.

From the aspect of energy saving, it is important to carry out the reconstruction of existing buildings. 50% of these buildings were built before the existence of any regulation on thermal protection.

There are numerous studies which were performed in the field of defining the optimum thermal insulation thickness. Some of

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Nomenclature

C	price [€]
f	function
k	overall heat transfer coefficient difference [W/m^2/K]
Δk	overall heat transfer coefficient [W/m^2/K]
n	number
q	heat flux per unit area [W/m^2]
Q	heat per unit area per year [Wh/m^2/year]
ΔQ	heat difference per unit area per year [Wh/m^2/year]
t	temperature [°C], [K]
T	time period per year [h/year]
Δt	temperature difference [°C], [K]
Greek	
α	convective heat transfer coefficient [W/m^2/K]
δ	thickness of thermal insulation layer [m]
Δ	difference [–]
λ	conductive heat transfer coefficient [W/m/K]
τ	time period [h]
Subscripts and superscripts	
i	input, investment
s	savings
o	output
m	middle/mean
w	wall
$isol$	isolation
$screw$	anchor screw
net	fibreglass network
$glue$	cement-based adhesive
pay	labour cost

them are based on the degree-days method. This is calculated as the difference between the base temperature and the mean outdoor air temperature.

Aslan et al. [1] conducted an energy analysis of different types of buildings in Gonen geothermal district heating system. Bektas et al. [2] investigated the effects of the wall type and degree-day values on the optimum insulation thicknesses for different insulation materials. The calculation was carried out for four different cities in different climate zones in Turkey. The cost of fuel decreases with the increase in insulation thickness. The total cost is the sum of the cost of fuel and insulation material. The optimum insulation thickness is determined as the minimum of the total cost curve. Galvin [3] carried out the thermal upgrades of existing homes in Germany in terms of the building code, subsidies, and economic efficiency.

Kaynakli [4] reviewed the economical and optimum thermal insulation thickness for building applications. Pacheco et al. [5] reviewed the energy efficient design of building.

Kalogirou et al. [6] energy analysed the buildings employing thermal mass in Cyprus. Ozel [7] analysed the cost for optimum thicknesses and environmental impacts of different insulation materials. The same author in article [8] dealt with the effect of wall orientation on the optimum insulation thickness by using a dynamic method. Chiraratananon and Hien [9] analysed thermal performance and cost effectiveness of massive walls under Thai climate. Uçar and Balo [10] determined the energy savings and the optimum insulation thickness in the four different insulated exterior walls. Bartal et al. [11] analysed the effect of the thermal insulation on the comfort sense using the static thermal comfort equation.

A number of authors in their work used the same “economic energy” method, including the next three. Bolatturk [12] determined the optimum insulation thickness for building walls with respect to various fuels and climate zones in Turkey. Çomakli and Yüksel [13] optimized the thermal insulation thickness of external walls for energy saving. Yu et al. [14] studied the optimum insulation thicknesses of external walls in hot summer and cold winter zone of China.

In the referred articles the optimization was mostly performed by using the “total cost” principle while the proposed method was based on “investment-savings” principle. It was proved that by applying both principles the obtained results were the same.

From the economic-energy efficiency point of view of the buildings, it is essential to use a thermal insulation layer to cover all external surfaces. The thermal insulation layer significantly reduces building heat loss. The reduction of losses depends mainly on the thickness of the thermal insulation layer.

Increasing the thermal insulation layer increases investment costs, but reduces the costs of exploitation. The costs for investment and exploitation have opposite tendencies. Thus, there is a technical-economic optimum of thermal insulation thickness.

The optimum can be found by applying appropriate mathematical model and an efficient mathematical method. From the standpoint of analysis, the important issue is to apply the appropriate method for displaying the results. The graphic display is one of the convenient forms of representation. The advantage of graphics is that it visually shows the solutions and the trends of solution change.

This paper analyses the energy-economic optimum thickness of thermal insulation layer for external brick wall. An appropriate mathematical model is required for the analysis. The model is composed of correlations to describe the cost of investment, exploitation and saving function. In the functions, the values are expressed in Euros. The dependent variables are the thickness of thermal insulation layers and the payback period of the investment.

In order to solve the model’s equations system a graph-numerical and an analytical-numerical method were applied. The pure analytical method is applicable to solve the equations system but it is rather complicated. The solutions are presented in the accompanying graphs for the cost of investment, exploitation and savings as a function of the time. The graphs show the optimum thickness of the thermal insulation layer and the payback period. The optimum is obtained by equating the function of investment and saving functions. The optimum thickness solution of thermal insulation layer is obtained only after the determination and substitution of the minimum payback period in the equated equation.

By applying the investment-savings principle and the developed new mathematical model, the optimum thickness of the thermal insulation layer for technical-economic conditions in Serbia is obtained. Based on current prices in Serbia in 2014, the energy-economic optimum thickness of thermal insulation layer-polystyrene is 6.89 cm which is rounded to ≈7 cm. Polystyrene can be bought in 1, 2, 3, . . ., 7, . . ., 10, . . . cm thickness only.

The payback period is 1.22 years if the price of electric energy is 0.09 [€/kWh]. The significant result is that if thickness is increased by 4.86 times investment increases only by 1.69 times. The results were verified by using two methods: the graphic-numerical and the analytical-numerical.

The aim of the future research is to find a simple analytical correlation for determining the optimum thickness of thermal insulation layer. Correlation would be applied by the practitioners.

2. The physical model

The considered physical system for techno-economic optimization consisted of an external wall with or without thermal