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Review

Thermoeconomic analysis method for optimization of insulation thickness for the four different climatic regions of Turkey

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ABSTRACT

Thermal insulation is one of the most effective energy-conservation measures in buildings. For this reason, the energy savings can be obtained by using proper thickness of insulation in buildings. In this study, the optimum thickness of insulation considering condensed vapor in external walls are found by using exergoeconomic analysis. The four various cities from four climate zones of Turkey, namely, Antalya, İstanbul, Elazığ and Erzurum are selected for the analysis. The optimum insulation thickness for Antalya, İstanbul, Elazığ and Erzurum are obtained as 0.038, 0.046, 0.057 and 0.0739 m at indoor temperature of 20 °C, respectively. The results show that the optimum insulation thickness at the indoor temperature of 18 and 22 °C are determined as 0.0663 and 0.0816 m for the city of Erzurum, respectively. The energy saving for the city of Erzurum is found as 77.2% for the indoor temperature of 18 °C, 79.0% for the indoor temperature of 20 °C and 80.6% for the indoor temperature of 22 °C, when the optimum insulation is applied.

1. Introduction

The energy consumption per capita of the majority of the population has been considerably increased especially in the developed world. In addition, energy growth in developing countries has been realized recently due to major developments in several sectors such as residential, industrial and agricultural areas. On the other hand, the primary energy sources, such as crude oil, natural gas and other conventional are limited resources formed by geological processes through solar energy accumulation into the earth over millions of years [1].

The energy consumption is distributed among four main sectors: industrial, building (residential/commercial), transportation and agricultural areas. The building sector is the largest energy consumer following the industrial sector. In many countries, the energy required for space heating and cooling in buildings has the highest share of all. Furthermore, energy saving and the effective usage of energy are very important in Turkey since she imports most of its energy. That's why, it is clear that effective thermal protection in building sector plays an important role towards the reduction of energy consumption for space heating and cooling [2].

Thermal insulation materials like other natural or man-made materials exhibit temperature dependent properties that vary with the nature of the material and the influencing temperature range. The impact of operating temperature on the thermal performance of insulation materials has been the subject of many studies. The results indicate that insulation materials subject to high temperature have higher thermal conductivity and therefore higher envelope cooling load with varying degrees depending on the type of insulation material [3]. Building insulation will reduce the operational cost of space heating at the expense of an increase in the initial investment by the added insulation material [4]. Many studies have been carried out on this subject to investigate the effectiveness of better thermal insulation for existing buildings to reduce energy consumption [5–8]. Yoon et al. [5] determined the impact of various insulation systems on the total cooling load of the cool storage structures with particular consideration given to the product thermal mass to find optimal insulation thicknesses for each envelope component for various climatic locations in Korea. They conducted to determine the optimal configuration for the storage building insulation system, life a cycle cost analysis. Al-Sallal [6] compared two types of roof insulation (polystyrene and fiberglass) in warm and cold climates and found that the payback period in cold climates is shorter than that in warm climates.

Life-cycle cost analysis is often applied to energy technologies and building projects. A life-cycle cost analysis can show that spending more initially on additional building insulation can

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produce a net savings (due to reduced heating and cooling costs) over the lifetime of a building. The concept of life cycle cost is used to determine the optimum insulation thickness in order to take into account the change in interest and inflation that directly affect both the cost of insulation materials and fuels. Çomaklı and Yüksel [7] investigated the optimum insulation thickness for the coldest cities of Turkey like Erzurum, Kars and Erzincan by life cycle cost analysis. They determined that energy saving was obtained when the optimum insulation thickness was applied. Dombaycı et al. [8] calculated the optimum insulation-thickness of the external wall for the five different energy-sources (coal, natural gas, LPG, fuel oil and electricity) and two different insulation materials (expanded polystyrene, rock wool) by life-cycle cost analysis. The results showed that the optimum result had been obtained by using coal as the energy source and expanded polystyrene as the insulating material.

The annual heating and cooling requirements of buildings in different regions can be obtained by means of the heating degree-days concept which is a well known and the simplest method. In this method, the heating or cooling degree-days are determined by using long-term measured data. However, this method becomes too crude and unreliable for buildings that experience large hourly and daily fluctuations, such as crowded office buildings. A dynamic method that considers solar radiation, infiltration, the thermal inertia of the building, and the variation of heat transfer coefficient and equipment efficiency needs to be used in such cases [9]. Cooling and heating degree-day concepts are among the most significant meteorological variables related to residential energy consumption [10].

Combining the second law of thermodynamics with economics (i.e., exergoeconomics) using energy or available energy (i.e., exergy) for cost purposes provides a powerful tool for systematic study and optimization of complex energy systems. Its goal is to mathematically combine in a single model, the first or second law of thermodynamic analysis with the economic factors [11]. Numerous studies have been undertaken to conduct energy, exergy and exergoeconomic analyses and also optimization of thermal systems [11–15]. Arslan and Kose calculated the optimum insulation thickness considering condensed vapor in existing buildings for Kutahya by using the thermoeconomic analysis [15]. They found that the optimum insulation thickness determined as 0.060, 0.065, 0.075 m with a rate of 74.9%, 76.3% and 78.8% in the energy saving for indoor temperature of 18, 20 and 22 °C, respectively.

Exergoeconomic evaluation is based on the concept of exergetic cost. For a thermodynamic system, the exergetic cost of an input, output or internal physical flow is defined as the amount of exergy per unit time required to produce that flow [16]. In this study, the optimum thickness of insulation considering condensed vapor in external walls are found by using exergoeconomic analysis. The exergoeconomic optimization is based on the cost of insulation materials and fuel. Then, a formula is developed for the economically optimal thickness determination of insulation and it is solved for four different climate cities of Turkey, using MATLAB optimization Toolbox. Turkey is divided into four climatic zones depending on average temperature degree-days of heating. In this study, the four different cities of Turkey, Adana, Istanbul, Elazığ, and Erzurum are selected to determine the optimum insulation thickness. These cities are chosen from four different climatic zones. The outdoor temperatures for the design heat load calculations have been considered in the range of −27 to 3 °C due to Mediterranean, Black sea and terrestrial climates in Turkey. For example, the outdoor temperature for the design purpose in Erzurum which is located in Turkey's Eastern Anatolia Region is −21 °C, while it is 3 °C for Antalya (located in Turkey's Mediterranean Region).

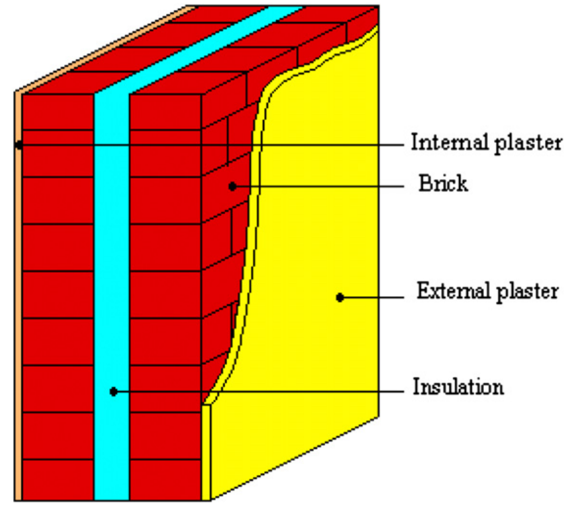

Fig. 1. Structure of the investigated external wall.

2. The structure of the external walls

The sandwich wall consists of an insulation layer in the middle of the two brick layers and two plaster layers on the inside and outside surfaces. The structure of sandwich wall consists of 2 cm inner plaster, two pieces of 8.5 cm horizontal hollow brick, insulation material and 3 cm external plaster. This structure is used in calculations for analyzed cities. The structure of sandwich wall is shown in Fig. 1. In the calculations, polystyrene was chosen as the insulation material.

3. Simulation

The growing concern of environmental problems has amplified both the significance of all kinds of energy saving measures, and the inevitability for an increased efficiency in all forms of energy utilization. Despite plenty of efforts made to improve energy efficiency in buildings, the issues of gaining an overall assessment and comparing different energy sources still exist. At present, analysis and optimization methods do not differentiate between different qualities of energy flows in building-related applications [17]. The exergy analysis is well known for optimization of energy conversion in large industrial and power plants [18,19]. Exergy analysis can help building designers to meet functionality and comfort requirements while keeping the associated energy resource depletion to a minimum [20,21]. Exergy provides a common basis for comparing the energy

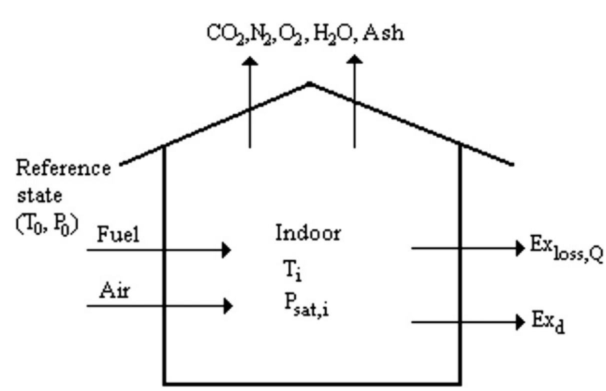

Fig. 2. Physical model of building system.