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Determination of optimum thickness of double-glazed windows for the climatic regions of Turkey

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ABSTRACT

In this study, the optimum air layer thickness of double-glazed windows is determined using the degree-days method. Calculations are obtained for İskenderun, Kocaeli, Ankara and Ardahan which are in different climate zones of Turkey. Heating cost of the objective function is calculated for natural gas, coal, fuel-oil, electricity and LPG. The optimum air layer thickness is obtained for three different base temperatures which are 18, 20 and 22 °C. The results show that the optimum air layer thickness varies between about 12 and 15 mm depending on the climate zone, fuel type and base temperature. The effect of the fuel type and the base temperature on the optimum air layer thickness diminishes in cold zones. It is shown that with a well-optimized glazed window, up to 60% energy saving can be achieved.

1. Introduction

The world energy demand is growing with increasing of population and growing economy. It is particularly important for Turkey since energy sources met only about 25% energy requirement; the rest is imported [1]. Therefore, energy saving has become compulsory. In Turkey, about 30% of total energy is used in the residential and commercial buildings [2]. Therefore, the energy saving in buildings should be focused on by a designer. 82% of energy is used for heating in the buildings in Turkey [3]. Energy loss from a typical building occurs 40% through external walls, 30% through windows, 17% through doors, 7% through roof, and 6% from floors [2].

Heat losses from external walls, roofs and floors can be reduced considerably using insulation materials. In the literature, there are a great number of studies to determine the optimum thickness of the insulation material depending on climate zones and energy sources. A systematic approach for optimization of insulation material thickness applied to Palestine was developed by Hasan [4]. It was based on the life cycle cost analysis. Generalized charts for selecting the optimum insulation thickness were presented as a function of degree-days and wall thermal resistance. Bolattürk [5,6], Dombaycı et al. [7], Kaynakli [8], Sisman et al. [9] and Ucar and Balo [10] obtained the optimum insulation thickness for various cities from different climate zones of Turkey considering different fuel types. Growing number of similar studies were done for different countries [11–14]. The annual energy requirement of buildings for heating or cooling can be obtained by means of degree-days method which is broadly used in energy consumption to plan and predict heating and cooling loads of buildings. This method can be defined simply as a quantitative reflection of the demand for energy needed to heat or cool spaces. Turkey has been divided into four different climate zones as defined in Turkish Standard Number 825 (TS 825) [15] and Buyukalaca et al. [16] presented degree-days data of the climate zones.

Although there are a great number of studies about the optimum thickness of the insulation material for the walls, there are few studies published about the optimization of glazing in buildings. As well-known, about one-third of the total heat loss of buildings occurs through windows which makes undesirable from an energy conversation point of view. One way to reduce the energy loss through window is to install double or triple pane windows. The energy saving can be further enhanced by replacing the air filled in the cavity between the two panes with an inert gas such as argon, krypton or xenon. Nearly half of the heat loss through a double-pane window is by radiation. Coating glass surfaces with a low-emissivity material is another method to reduce the energy loss from double-glazed windows.

Installing double or triple pane window introduce stationary air layer in the glazing unit which decreases the conduction heat transfer. However, increasing the air layer thickness further a critical value initiates convection currents in the enclosed air space, which increases the heat transfer and thus defeats the purpose [17]. Korpela et al. [18] published a numerical study about heat transfer through a double-pane window using finite difference method and presented detailed plots of the stream patterns and isotherms. Aydın [19,20] also presented numerical studies to determine the

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critical value of air layer thickness between two panes for different climate zones of Turkey considering only the amount of energy. The calculations given in [19] showed that the optimum air layer thickness between panes varies from 12 to 21 mm depending on the climate zone. The effect of the convection boundary conditions for the outer surfaces was investigated in [20]. The new boundary conditions reduced the optimum air layer thickness given in [19]. Soylemez [21] presented a thermoeconomic optimization analysis yielding a simple algebraic formula for estimating the optimum number of panes for windows. The overall heat transfer coefficient values were correlated for single, double, triple and quadruple pane windows that are used in HVAC and refrigeration applications. The effect of the gas type between panes and frame materials on the energy loss was investigated by Weir and Muneer [22].

To the best knowledge of authors only energy loss is considered on the determination of the optimum air layer thickness in the literature. Increasing the air layer thickness decreases energy; however, it increases the investment cost of the framing of the window. The heat transfer rate of a single-glazed window is about 2.5 times higher than which of a double-glazed window. Consequently, installing double-glazed windows can reduce both a significant amount of energy and an environmental pollution. However, approximately 87% of the buildings have single-glazed windows, 9% have double-glazed, and only 4% have low-e glass in Turkey [23]. Therefore, properly designed double-glazed windows should become widespread all over the country. Some parameters such as investment cost, indoor and outdoor temperatures, fuel price for the heating and the present worth factor (*PWF*) influence the optimum value of the air layer thickness. The aim of this study is to determine the optimum air layer thickness of double-glazed windows considering the both heating and investment costs. It has been found that there are commonly two types of double-glazed window which has 12 and 16 mm air layer thickness in the production list of Turkish companies. Each type of double-glazed windows can be seen easily in every city of Turkey which shows that the climate conditions are not considered as a decision parameter in the installation of the double-glazed windows. In this study, to see the effect of the climate conditions on the determination of the air layer thickness for the glazing, İskenderun, Kocaeli, Ankara and Ardahan located in different climate zones are chosen as model cities. Also, the effect of the five different fuel types is considered to determine the optimum air layer thickness. To do so, an objective function of the economical model is outlined in Section 2 and the parameters are given in Section 3. The calculated results are compared in Section 4.

2. Method

In this study, the optimum air layer thickness is determined considering the investment cost and the energy cost due to heat loss from window. Heat loss (q) from per unit area through the window is determined according to Eq. (1):

$$q = U(T_b - T_o) \quad (1)$$

Here U is the overall heat transfer coefficient, T_b is the base temperature and T_o is mean daily temperature. The summation of Eq. (1) during heating season will be the heating energy. In this study, for simplicity, Eq. (2) is used to obtain the heating energy according to the degree-day method [16]:

$$E = 86400\, DDU \quad (2)$$

where DD is the degree-day sum. Considering the heating system efficiency, η_s, the energy demand is given as:

$$E_A = \frac{86400\, DDU}{\eta_s} \quad (3)$$

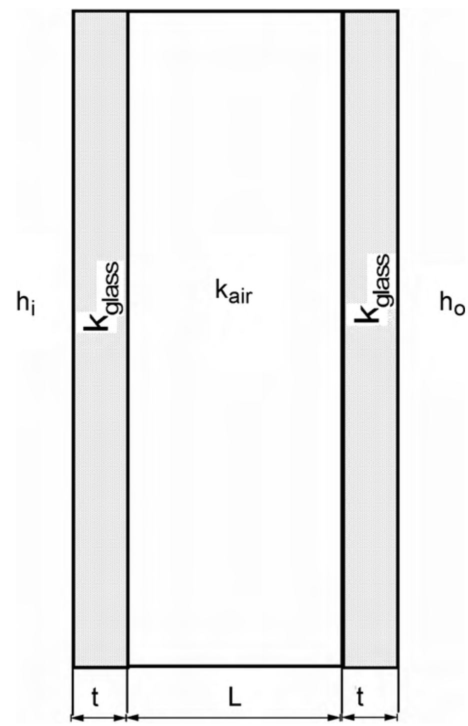

Fig. 1. Geometry of a double-glazed window.

Schematic representation of a double-glazed window is shown in Fig. 1 and the overall heat transfer coefficient (U) of a double-glazed window is defined in Eq. (4):

$$U_D = \frac{1}{(1/h_i) + (t/k_{glass}) + (1/h_{space}) + (t/k_{glass}) + (1/h_o)} \quad (4)$$

here h_i (=8.29 W m^{-2} K^{-1}) and h_o (=34 W m^{-2} K^{-1}) are the heat transfer coefficients at the indoor and outdoor surface of window, respectively [17], t is the thickness of the glass which is taken as 4 mm for both single and double-glazed configurations and k_{glass} (=0.92 W m^{-1} K^{-1}) is the thermal conductivity of the glass. Nearly half of the energy passes through the window is transferred by radiation and the rest by conduction or convection. So, h_{space} (=$h_{radiative} + h_{convective}$) is the combination of radiative and convective heat transfer coefficients in the air layer between the panes. The term $1/h_{space}$ in Eq. (4) represents the overall thermal resistance of the trapped air layer. Disregarding the thermal resistances of glass layers in Eq. (4), the heat transfer coefficient at the center of glass given by [24] is as shown in Fig. 2.

There is a critical value for the air layer thickness which minimizes the heat loss as seen from Fig. 2. The heat passes through the window by conduction mechanism below a critical air layer thickness. Beyond the critical thickness, the heat transfer mechanism transforms to convection that causes increase in the U-factor. For a specified glass material, the effect of the air layer thickness on the radiation heat transfer is negligible. However, the total heat transfer rate will be affected significantly by the emissivity (ε) of the glass materials. In this study, the calculations are done for an ordinary glass material (ε = 0.84) and the effect of the emissivity on the objective function is not considered. The overall heat transfer coefficient given in Eq. (4) can be rewritten for the objective function of this study by correlating data shown in Fig. 2:

$$U = 0.0074L^2 - 0.2179L + 4.3581 \quad (5)$$

Here L (mm) is the air layer thickness. The correlation coefficient of Eq. (5) is R^2 = 0.98. Overall heat transfer coefficient for a single-