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Evaluation of building energy performance with paper waste reinforced clay brick

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Abstract – In this paper, a thermal insulation analysis was carried out for a building using paper waste reinforced clay brick as building material. Firstly, the analysis was made using two different normal wall bricks as building material for the sample building. Later, the analysis was carried out for the reference paper waste reinforced clay brick, and the results of these two cases were compared. Within the scope of analysis, depending on the building material used, the brick thickness was changed at certain ratios for both cases, and changes due to thickness, specific heat loss and total heat need were observed with Engineering Equation Solver (EES) program. As a result of these observations and analyzes, it was concluded that the use of paper waste reinforced clay brick instead of using two different standard wall bricks as building materials significantly reduced the total energy requirement. Moreover, the result of this study shows us that, since the use of bricks made of waste and brick instead of normal wall bricks as building material is produced from natural sources as well as contributing to recycling and associated energy saving; it is inevitable to contribute to a healthier insulation since it has both a low production cost and a lower heat transfer coefficient.

Keywords – thermal insulation, clay brick, paper waste, thermal performance, energy performance

I. INTRODUCTION

In the world where energy demand is constantly increasing but resources are declining, the importance of energy production is crucial as well as the conservation and unconscious consumption of energy and its economic use. The vast majority of energy losses in the world stem from buildings. Energy efficiency and energy saving of buildings have been one of the most important issues mentioned in the world because they affect our comfort and our economy closely. Because the consumption of energy from buildings accounts for about 33% of the total energy consumed in Turkey and EU countries, and half of the losses occur from the wall surfaces of the buildings [1]. Although the heat losses from the walls can not be totally destroyed, it is possible to reduce the most. This can only be achieved by applying thermal insulation. For this reason, thermal insulation is very important and various insulation materials and building materials with different heat transfer coefficients are used in insulation.

Insulation materials that have widespread use in building constructions are usually made up of materials that are not renewable sources. These materials, which generally require high energy consumption in production, lead to problems in the recycling stage after the end of its life [2]. Therefore, the development and implementation of recycled building materials can contribute to the minimization of environmental impacts of buildings, reducing both energy consumption during and after use of buildings. Moreover, recycling of waste is inevitable for sustainable life around the world, as it encompasses various areas of interest such as economy, environment, engineering and social life [3]. In this regard, many researches have been done within the context of the insulation materials used in the buildings. For example:

M. Sutcu et al. [1] examined the thermal behaviors of hollow clay bricks made of paper waste and optimized the heat performance. By observing the strength and thermal properties of different paper waste concentrations by laboratory tests, it was observed that the thermal conductivity of the additive and microporous brick materials decreased from 0.68 W/mK to 0.39 W/mK compared to the non-additive sample. It has also been applied to nonlinear numerical thermal analysis of three different cavities, including radiation and convection in brick holes. They concluded that the reduction of the material heat conductivities of the briquettes at all times analyzed and the reduction of the radiation emissivity of the surface of the recesses resulted in a decrease in the thermal conductivity of the bricks.

A. K. Mandal et al. [4] investigated the suitability of insulation bricks made of fly ash and red sludge wastes for insulation. Within the scope of this study, they investigated the effect of ignition temperature and chip mix on the physical properties of bricks, depending on the changing waste rate, and observed that the high ignition temperature increased the strength of the bricks. As a result, they concluded that bricks made from these wastes were suitable for insulation in environments up to 600 ℃.

A. N. Adazabra et al. [5] examined the feasibility of replacing clay materials with spent timber waste as an economical and sustainable building material by evaluating the technological properties of fired brick bars. In this context, they have mixed different amounts of raw shear wastes with raw clay materials and have made examinations by replacing 5-20% of clay material with wasted timber waste. As a result of the necessary reviews, they came to the conclusion that used shea wastes could be used as raw materials in the energy contribution to the construction brick, thus creating new road possibilities for economically sustainable use in the construction sector.

This study is very important for the recovery of energy resources lost by energy efficiency and waste recycling as a result of using recycled paper waste and brick produced from clay as building material. In this study, three different bricks with different thicknesses and heat transfer coefficients were used as building elements for a sample building, and the thicknesses of these bricks were changed in d = 0.1m – 0.25m, and energy loss and energy need analysis related to these bricks were performed. In addition, the properties of these bricks are discussed in detail in the material and methods section.

In the study, firstly information was given about the building to be analyzed. Later on, this sequence follows the bricks and properties to be used in the study, the calculation method and the results achieved.

II. Materials and Method

A. Building to be analyzed in the study

With reference to this study, the house have been built as a two floors masonry which located in the third degree day zone and ten meters wide from outside to outside, twelve meters long and height of six meters is shown in Figure 1. Also, window area 20 m^2 on the building and exterior door area 2m^2

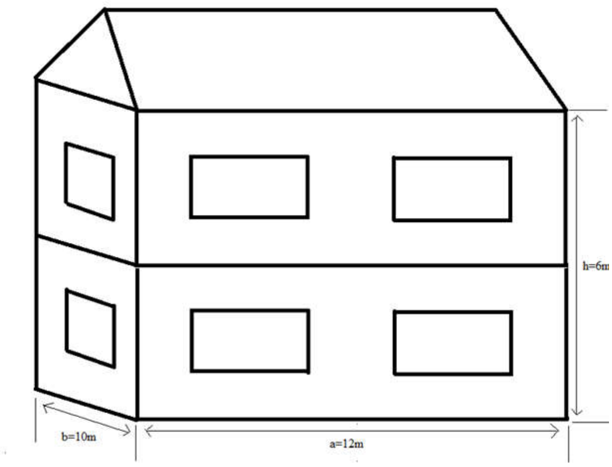

Fig. 1 . The building analyzed in the study

B. Bricks and properties to be used in work

In this study, three different bricks for comparison were used for the application of a sample building as building material. The first two are the normal wall bricks, the other is the paper waste reinforced clay brick. Clay bricks are of rectangular section and are like the chemical composotion of these bricks: %61.7 SiO_2, %15.7 Al_2O_3, %0.8 TiO_2, %6.8 Fe_2O_3, %2.4 K_2O, %2,1 CaO, %2.3 MgO and %0.3 Na_2O. The chemical composition of the recycled paper waste used in brick making is as follows: %6.4 SiO_2, %4.1 Al_2O_3, %0.1 TiO_2, %0.3 Fe_2O_3, %0.1 K_2O, %32.9 CaO, %1.5 MgO and %0.1 Na_2O. As it is understood from the values, the minerals in the brick contain a lot of quartz and clay minerals. Paper wastes mainly contain calcium carbonate, cellulose and a small amount of clay [1].

C. Calculation method

Providing thermal conditions is important for thermal comfort. To improve the thermal conditions, problems caused by building facades should be eliminated. In doing so, it is important to use minimum energy [2]. For this reason, it is necessary to observe the energy saving firstly when doing heat insulation.

In this study, the insulation and related energy requirement for the sample building was made using the energy loss analysis Engineering Equations Solver (EES) program. Within the scope of the analysis, heat losses from wall surfaces, reinforced concrete, ceiling, floor, doors and windows were investigated individually. In addition, solar energy gains are calculated and the building's annual heating energy requirement is achieved. All these calculations and results have been obtained by following the path. First, with the help of EES program, thermal insulation analysis was done by calculating all the heat losses and gains for the sample building where standard brick was used as building element. The same process is then carried out for the same building with recycled paper waste reinforced clay brick; a yearly total heat loss, heat demand and solar acquisition rates have been analyzed. Finally, the brick thickness used was compared at d = 0.1 m - 0.25 m and the gains achieved in terms of energy were determined when were used paper waste reinforced clay brick as building material.

The most general equations that form the basis of the analysis can be described as Eqs. 1- 3 [7] and 3-8 [6]. The amount of heat energy transferred from unit time can be calculated by the following equation:

$$Q = \frac{A.\Delta T}{R} \tag{1}$$

Where Q, A, ΔT and R are respectively, the unit temperature transient (Watt), the surface area through which heat is passed (m^2), the temperature difference (℃ or K) and the thermal resistance (m^{2}K/W).

Total heat transfer coefficient can be defined as:

$$U = \frac{1}{R} \tag{2}$$

Where U and R are respectively, total heat transfer coefficient (W/m^{2}K) and thermal resistance of the wall (m^{2}K/W).

$$R = \frac{1}{h_{in}} + \frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{d_3}{k_3} + \cdots + \frac{1}{h_{out}} \tag{3}$$

Where h_{in} and h_{out} are respectively, surface heat transfer coefficient on inner and outer surfaces (W/m^{2}K). d_{1-2-3} are represent the thickness of the structural component (m) and k is the thermal conductivity coefficient (W/m^{2}K).

The specific heat loss of the building can be defined as:

$$H = H_T + H_v \tag{4}$$

Where, H, H_T , H_V are respectively, total specific heat loss (W/K), heat loss through conduction and convection (W/K) and heat loss through ventilation (W/K).

$$H_T = \sum AU + lU_l \tag{5}$$

$$\sum AU = U_D A_D + U_P A_P + U_K A_K + 0.8\, U_T A_T + 0.5 U_t A_t + U_d A_d + 0.5\, U_{ds} A_{ds} \quad (6)$$

Where, U_D, U_P, U_K, U_T, U_t, U_D, U_{ds}, A_D, A_p, A_K, A_T, A_t, A_d, A_{ds} respectively, thermal conductivity coefficient of outer wall (W/m^{2}K), window thermal conductivity coefficient (W/m^{2}K), thermal conductivity coefficient of outer door (W/m^{2}K), thermal conductivity coefficient of the ceiling (W/m^{2}K), coefficient of thermal conductivity of the upholstery on the floor (W/m^{2}K), coefficient of thermal conductivity of the floor in contact with the outside air (W/m^{2}K), thermal conductivity coefficient of building components in contact with indoor environments at low temperatures (W/m^{2}K), outside wall area (m^2), window area (m^2), outer door area (m^2), ceiling area (m^2), floor area (m^2), outside air-contacting floor/upholstery area (m^2), is the area of building elements that come into contact with indoor environments at low temperatures (m^2). *I* is refers to the heat bridge length (m) and U_l is refers to the linear permeability of the heat bridge (W/mK).

$$H_V = \rho . c . V' \quad (7)$$

Where ρ is unit volume of air (kg/m^3), c is specific heat of the air (J/kgK) and V' is volumetric air change (m^3/h).

The monthly average solar energy gain is calculated with the following equation:

$$\emptyset_{ay} = \sum r_{i,ay} \times g_{i,ay} \times I_{i,ay} \times A_i \quad (8)$$

Where, $r_{i,ay}$ is i mean average shading factor of transparent surfaces in i direction, $g_{i,ay}$ is the solar energy transmission factor of the i-direction transparent elements, $I_{i,ay}$ is monthly mean solar radiation intensity from vertical surfaces in i direction (W/m^2) and A_i is total window area in the i direction (m^2).

III. Results

In this section, the effect of using recycled paper waste reinforced clay brick made from thermal insulation in the energy analysis is realized according to TS 825 standard. The graphs resulting from the analysis are shown in this section.

The variation of the specific heat loss due to the brick thickness is shown in Fig. 2, when a typical building uses normal wall bricks and paper wastes and brick bricks as building material.

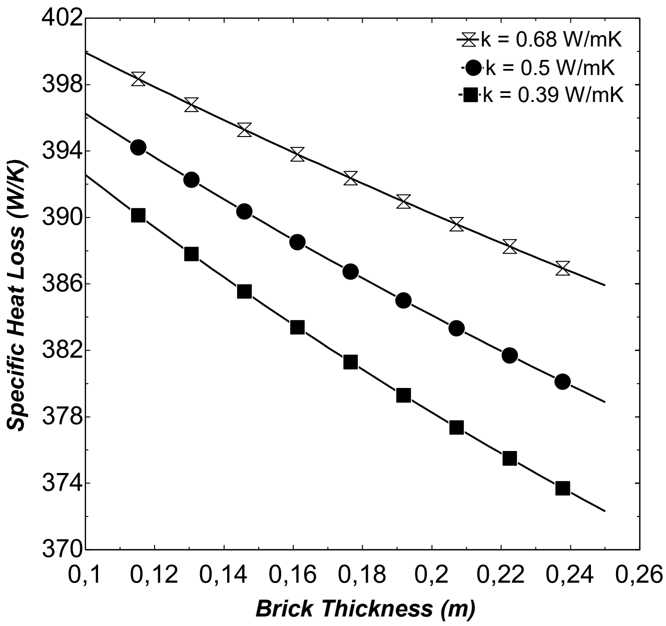

Fig. 2. Change in specific heat loss due to brick thickness

This figure makes it clear that the specific heat loss is significantly reduced when the brick thickness is changed in an increasing direction. It is also observed that if we compare the three bricks at the same thickness by going out of the way, the clay brick made of paper waste is preferred as the building material of the building, it reduces the specific heat loss to a considerable extent.

Figure 3 shows the change in the total heat demand due to the brick thickness when clay bricks made of two different standard wall bricks and wastes are used in the context of building material. As can be seen, when clay bricks made of waste are used as building material, a significant reduction in the total heat requirement for one year is realized.

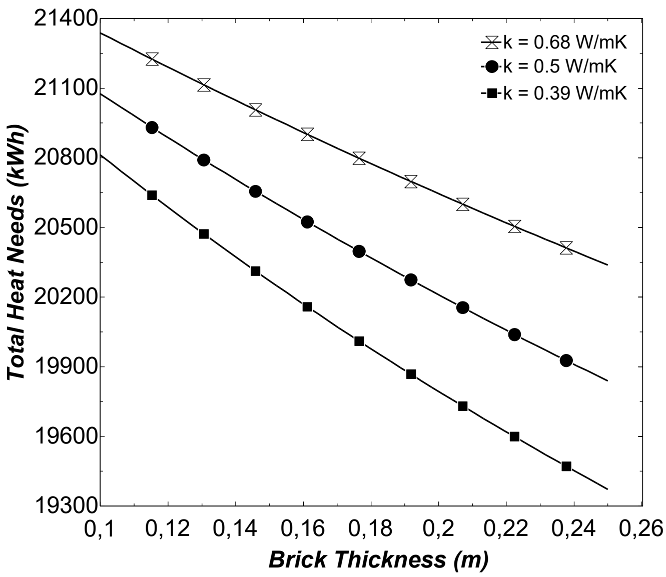

Fig. 3. Change in total heat need due to brick thicknes

IV. Discussion

It is inevitable that the brick made of waste and clay will have many advantages with the preference in heat insulation by going out from all the evaluations.

Instead of the normal wall bricks, depending on the use of brick made of waste and clay, in one year, approximately respectively; it has been observed that the specific heat loss decreased by 3.53% and the total heat need decreased by 4.75%. In this context, the use of these bricks has reduced total heat loss by minimizing heat losses.

This brick, which saves both energy and cost, will cost less than other bricks. Because this brick is made of waste materials and clay instead of artificial material. Therefore, the use of these bricks is also of great importance in order to restore wastes. This is an important place for the efficient use of energy and the recycling of wastes.

V. CONCLUSION

In this study, energy and cost analysis were carried out by emphasizing the importance of insulation of building materials used in buildings. The main results of the study can be summarized as follows:

- First of all, thermal insulation is important in terms of reducing worldwide energy loss and ensuring energy savings. If the insulation is made using the right insulation techniques, depending on the area where the structures are located, it will be an important step for the improvement of our country and the world economy.
- The properties of building materials are also very important if they are as important as the properties of thermal insulation materials used in thermal insulation techniques applied in buildings. Because, heat losses are also important in building materials.
- When it is preferred to use as paper waste reinforced brick building material which is expressed in the study, it has an important place in terms of energy conservation because it increases energy saving.
- Finally, as is the case in this study, if the thermal insulation material and construction material requirements are obtained and used from natural resources and recycled wastes, in the worrying world of the future, a major step will be taken towards becoming a society with a focus on recycling.

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