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Full Length Research Paper

Heat gain through Trombe wall using solar energy in a cold region of Turkey

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In this study, heat gain from solar energy through Trombe wall was investigated in Turkey. The wall materials, reinforced concrete, brick and autoclaved aerated concrete, were taken into consideration with various surface colours. The passive heating potential of Trombe wall was estimated by using unutilizability method which is used in the designs of passive systems for heat gain. The results indicated that the annual heat gain from solar energy through Trombe walls was found out to be between 26.9 to 9.7% for concrete, 20.5 to 7.1% for brick and 13.0 to 4.3% for aerated concrete in different surface colours.

Key words: Solar energy, Trombe wall, energy consumption, energy gain.

INTRODUCTION

A great amount of energy consumption occurs in buildings due to indoor heating, cooling, ventilation and lighting. Among these, the energy consumed for heating in buildings has the biggest proportion (40%) of consumption. For that reason, it is crucial to decrease the energy consumption and its environmental effects. It is also inevitable to use clean, inexhaustible and emission free sources for energy gain in order to provide energy efficiency and conservation. One of theose sources is solar energy utilized in architectural applications for sustainability. In this context, proper structure elements need to be considered for utilizing solar energy in active or passive ways and for decreasing energy losses. By using passive solar devices in the building design, the energy requirement of buildings can be reduced to a great extent. In passive design, the direction and location of buildings and the characteristics of building materials are the criteria which need to be taken into account. It is known that since the ancient times, people have used thick walls of adobe or stone to trap the sun's heat during the day time and release it slowly and evenly at night to heat the buildings. Today's low-energy buildings often develop on this ancient technique by incorporating a thermal storage and efficient (delivery) system called Trombe wall (named after French inventor Felix Trombe in the late 1950s), which continues to serve as an effective feature of passive solar design (Torcellini and Pless, 2004).

Many theoretical and experimental studies have shown that indoor comfort is improved due to well-designed Trombe walls (Jie et al., 2007). Most of the studies on Trombe wall are concerned with its winter heating. Smolec and Thomas (1991) have implemented theoretical calculations for the temperature distribution of a Trombe wall by using a thermal network and compared the results with the experimental data. Fang and Li (2000) compared the Lattice Passive Solar Heating Walls with traditional Trombe wall. In their study, some parameters such as the optical features of surface and transparent cover, the thickness of wall materials, the thermal conductivity and the distribution of ventilation holes were examined. In consequence of the experimenttal and theoretical study, thermal efficiency on Trombe wall was found out to be 22.6 and 30.2% in solar wall. Buzzoni et al. (1998) performed numerical simulation for the Trombe wall application with thermal insulation on the southern wall and two solar ducts, and these numerical results were compared with experimental data. Chen et al. (1994) applied shading elements on air gap in a building in Dalian in order to increase the thermal performance of Trombe wall. They examined the temperature change during the night time in winter months. They found out that the heat loss in air g ap decreased about

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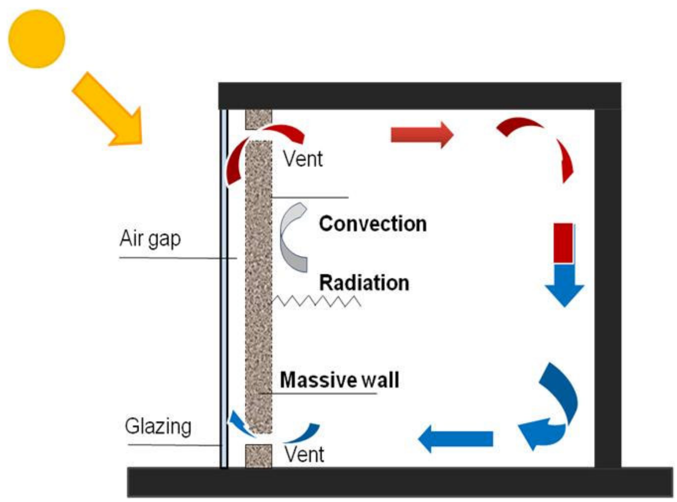

Figure 1. Working principle of a traditional Trombe wall and energy gain.

20 to 40% and Trombe wall prevented heat flow into outdoor. Moreover, they observed that the exterior temperature of the Trombe wall got increased. Chen et al. (2006) examined the airflow in a Trombe wall and presumed that the airflow is the function of the height of the air duct. In another study by Sodha et al. (1981), the thermal performance of Trombe walls and roof pond systems was investigated for passive heating and cooling of a building. Raman et al. (2001), in their study, developed a passive solar system, which can provide thermal comfort through-out the year in composite climates. Chel et al. (2008) investigated energy conservation and reduction of CO_2 emissions through Trombe wall in a honey storage building. They investigated the benefits of Trombe wall applications for winter heating months. By using TRNSYS building simulation software, they estimated the passive heating potential of Trombe wall for a honey storage building. It was concluded that there has been potential of energy conservation up to 3312 kWh/year and associated reduction in CO_2 emissions (33 ton/year) through a Trombe wall. The payback period was assumed to be about 7 months.

In Turkey, energy consumption for heating is extremely high because heat insulation applications on building walls/roofs are not widespread and solar energy is not used efficiently for energy gain. Therefore, in this paper, solar energy gain for buildings through Trombe wall for winter heating application on a sample building in Erzurum, a city in the coldest region of Turkey, was investigated. For calculating heat gain through Trombe wall, the characteristics of the sample building were displayed. Firstly the heat gain/loss of the building was calculated in accordance with TS 825 (Heat Insulation Rules in Buildings-Turkey). It is seen that TS 825-2008 defines four PW HDD zones with a 19°C base temperature for the locations in Turkey. According to TS 825 regulation, Erzurum (latitude: 39°55'N, longitude: 41°17'E, altitude: 981 m) which is located in cold climatic zone (zone 4) having 4888 heating degree-days has great heating load. In addition, solar radiation rate is high in Erzurum due to the altitude. Therefore, solar energy can be potentially utilized for heating in this region. In this context, energy gain from solar radiation for heating purposes with Trombe walls by using different wall materials (concrete, brick, aerated concrete) and surface colours (dark, natural, light) was calculated. It is aimed at showing the passive use of solar energy with architectural elements and the impact of material choices on energy gain. Using renewable energy has a growing importance in case of decreasing energy demand of buildings and reducing CO_2 emissions for sustainability.

WORKING PRINCIPLE OF TROMBE WALL

The developments in the application of principles `low-energy' architecture by using less energy have spread worldwide, which is highly positive since they contribute to improve not only the environment but also the living quality of human beings (Lucas et al., 2009).

Trombe wall, as an effective passive solar building facade system, has received much attention in the past decades. Its applications are simple and economical and are suitable for locations in a wide range of latitudes. A typical Trombe wall comprises a massive thermal wall with a clear outer glazing and a convective air gap in between (Jie et al., 2007). The massive thermal wall serves to collect and store solar energy. Heat from sunlight during the day passing through the glass is absorbed by the dark surface, stored in the wall and conducted slowly inward through the massive wall with a time delay. High transmission glass maximizes solar gains to the massive wall (Torcellini and Pless, 2004). The stored energy is transferred to the inside of the building for space heating or facilitates air movement for space cooling. The space heating/cooling performance depends on the thermal conductive behavior of the massive wall and the airflow characteristics in the convective air cavity and in the room space itself (Figure 1).

Although Trombe wall applications have been used worldwide and had many improvements in the past decades due to some advantages such as simple configuration, high efficiency, zero running cost (Yakubu, 2001), its application has been restricted because of its black-matt surface of massive wall underneath the glass. Among users, it has not been accepted as aesthetic. As an architectural detail, patterned glass can limit the exterior visibility of the dark wall surface without sacrificing transmission (Torcellini and Pless, 2004).

Further, Trombe walls are presumed to cause over-heating in summer months. In order to prevent over-heating, sliding panels, shading devices can be located or air circulation must be supplied. Besides, in order to

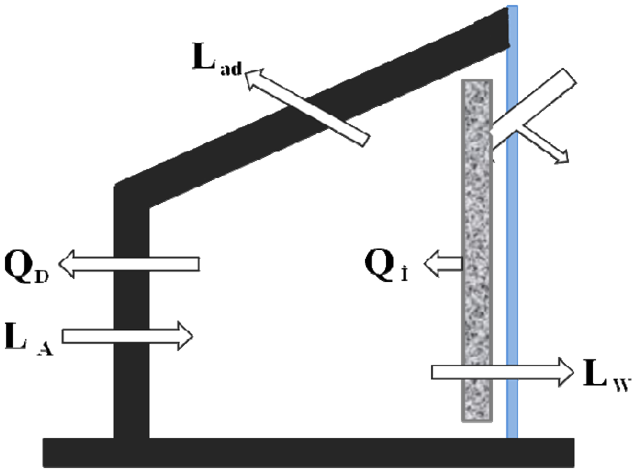

Figure 2. Monthly energy flows for a Trombe wall.

solve these issues, a novel Trombe structure with PV cells module known as a PV-Trombe wall was designed by Jie et al. (2007).

METHODOLOGY

The unutilizability method (UU method)

UU method establishes the limiting cases of zero and infinite capacitance building. A real building that lies between these two limits is determined by correlations based on simulations. The first case is that construction materials have the capacity of infinite heat storage. In the latter one, construction materials do not have the capability of energy storage. By using UU method, it is possible to calculate auxiliary energy requirement for UU method developed for direct gain systems and applied for collector storage wall systems (Trombe wall) by amendments.

Calculations were carried out by using monthly average values. The annual auxiliary energy required for the buildings which are heated in passive ways is also obtained through this calculation method. The monthly energy flows for the buildings on which Trombe wall is applied are displayed in Figure 2 (Duffie and Beckman, 1991).

The heating loads are shown in two parts. The load L_{ad} would be experienced if an adiabatic wall replaced storage wall (Raman et al., 2001). The load L_w is the monthly energy loss from the building through the storage wall that would be experienced if the transmittance of the glazing for solar radiation were zero and it can be estimated by Duffie and Beckman (1991).

$$L_{ad} = (UA)_{ad}\,(DD) \tag{1}$$

$$L_W = U_W\, A_r\,(DD) \tag{2}$$

The monthly average of outer wall temperature ($\bar{T}_w$) and net monthly transmitted energy to the building (Q_n) are calculated by establishing monthly average daily energy equilibrium on the outer surface of Trombe wall (Duffie and Beckman, 1991):

$$\bar{S} = U_k\,(\bar{T}_w - \bar{T}_i)\,\Delta t + U_L\,(\bar{T}_w - \bar{T}_d)\,\Delta t$$

This can be used to calculate the net monthly heat transfer to the building:

$$Q_n = U_k\, A_r\,(\bar{T}_w - T_i)\,\Delta t\, N \tag{4}$$

For a hypothetical building with infinite thermal capacitance, all of the net gain Q_n can be used. For monthly energy balance on this infinite thermal capacitance (Duffie and Beckman, 1991) is

$$L_{Ai} = (L_{ad} - Q_n)^{+} \tag{5}$$

A hypothetical building having zero thermal capacitance in the storage wall has the maximum auxiliary but not the time of the solar gains to the building (Duffie and Beckman, 1991). A monthly energy balance on this zero-capacitance building gives:

$$L_{Az} = (L_{ad} - Q_n + Q_D)^{+} \tag{6}$$

where, Q_D, the energy dumped, is the monthly energy entering building through the wall that does not contribute to reduction of the auxiliary energy requirement (Duffie and Beckman , 1991; Kianifar and Rezazadeh, 2007).

Here Q_D can be determined by integrating $\dot{Q}_D$, the rate at which excess energy must be removed to prevent the indoor temperature from rising above the low thermostat set temperature is calculated by:

$$\dot{Q}_D = [U_k\, A_r\,(T_w - T_i) - (UA)_{ad}\,(T_d - T_b)]^{+} \tag{7}$$

An energy balance on the absorbing surface of the hypothetical zero thermal capacity storage walls at any time gives:

$$I_T\,(\tau\alpha)\,A_r = U_L A_r\,(T_w - T_d) + U_k\, A_r\,(T_w - T_i)$$
(8)

Where the critical radiation level I_{TC} makes $\dot{Q}_D$ zero is given by:

$$I_{TC} = \frac{1}{(\bar{\tau\alpha})\,A_r}\left[(UA)_{ad}\left(\frac{U_L}{U_k}+1\right)\frac{T_b - \bar{T}_d}{T_r - \bar{T}_d} + U_L\, A_r\right](T_i - T_d) \tag{9}$$

Thus:

$$Q_D = \frac{(U_k\, A_r\, \bar{S}\, N\, \bar{\phi})}{(U_L + U_k)} \tag{10}$$

Equations (1) and (2) provide estimates of the limits of the performance of storage wall systems (Yang et al., 2000). The solar fractions corresponding to the limits are defined as:

$$f_i = 1 - \frac{L_{Ai}}{L_{ad} + L_w} = \frac{L_W + Q_i}{L_{ad} + L_W} \quad (11)$$

and

$$f_Z = 1 - \frac{L_{Az}}{L_{ad} + L_w} = f_i - \frac{U_k}{U_L + U_k}\bar{\phi} X \quad (12)$$

Where the solar load ratio is defined as:

$$X = \frac{\bar{S}\ N\ A_r}{L_{ad} + L_W} \quad (13)$$

In order to establish where between these limits exist, a real system will operate, correlation methods are used. Building thermal storage capacity for a month is calculated through a parameter of the storage capacity of the building and the wall (Tsilingiris, 2002, 2004; Ahlama et al., 1997).

A correlation for monthly solar fraction *f* which is defined as [*1 – L_A / (L_{ad}+L_W)*] is a function of f_i and a dimensionless storage-dump ratio, then:

$$Y = \frac{S_b + 0{,}047\, S_W}{Q_D} \quad (14)$$

The correlation for *f* is defined as:

$$f = \min\{P\, f_i + 0{,}88(1-P)[1-\exp(-1{,}26\, f_i)], 1\} \quad (15)$$

The equation of solar fraction is:

$$P = [1-\exp(-0{,}144\,Y)]^{0{,}53} \quad (16)$$

Monthly energy requirement is calculated by the following equation:

$$Q_A = (L_{ad} + L_w)(1-f) \quad (17)$$

Utilizability concept

Utilizability can be thought of as a radiation statistics that has been built into its critical radiation levels. The ϕ and $\bar{\phi}$ concepts can be applied to a variety of design problems for heating systems, combined solar energy-heat pump systems and many others. The concept utilizability has been extended to apply to passively heated buildings, where the excess energy (unutilizable energy) that cannot be stored in a building structure can be estimated.

The amount of calculations in the use of ϕ curves led by Klein (1978) to develop the concept of monthly average daily utilizability $\bar{\phi}$ (Klein, 1978). This daily utilizability is defined as the sum for amount (over all hours and days) of the radiation on a tilted surface that is above a critical level divided by monthly radiation.

The daily utilizability $\bar{\phi}$ that is given by following equation:

$$\bar{\phi} = \frac{\sum_{day}\sum_{hour}(I_T - I_{TC})^+}{\bar{H}_T\, N} \quad (18)$$

Calculating solar radiation

Isotropic model was used for calculating monthly average daily total radiation on the surface where Trombe wall was applied. The intensity of the diffused radiation in isotropic model was assumed to be uniform in the sky and the diffusion was not deduced to occur due to azimuth and zenith angles. By using the data of total solar radiation on the horizontal surface, the radiation values on vertical surface which is south oriented were calculated (Duffie and Beckman, 1991). The monthly average absorbed radiation $\bar{S}$ can be calculated with the equation below:

$$\bar{S} = \bar{H}_b \bar{R}_b (\overline{\tau\alpha})_b + \bar{H}_d[(1+\cos\beta)/2](\overline{\tau\alpha})_d + \rho\left(\bar{H}_b + \bar{H}_d\right)[(1-\cos\beta)/2](\overline{\tau\alpha})_g \quad (19)$$

An isotropic-diffuse assumption is used for the diffuse and ground reflected terms, $(\overline{\tau\alpha})_b$ and $(\overline{\tau\alpha})_d$ can be evaluated by using the effective incidence angle. The functions of properties of the cover and absorber and the collector slope β do not change with time (Duffie and Beckman, 1991).

TROMBE WALL APPLICATION IN A DWELLING HOUSE

Building construction details

In the study, a two storey building with 118.7 m^2 floor area of which structural system is reinforced concrete carcass was selected. The building plan and section view are shown in Figure 3. The parameters about construction materials are displayed in Table 1.

As seen in Figure 4, Trombe wall was applied on the south facade of this building. The height of the south oriented Trombe wall is 2.7 m and its width is 9.1 m. Trombe wall consists of double glazing (6 – 16 - 6 mm) and a massive wall is constructed with reinforced concrete, brick and autoclaved aerated concrete in different thicknesses and surface colours. The wall thicknesses are 25 cm in reinforced concrete, 19 cm in brick and 15 cm in AAC. Also, inner plaster is 2 cm; outer plaster is 3 cm. Wall surface colours were deduced as dark, natural and light due to different absorption coefficients of those colours (Figure 5). The thermal properties of the construction materials used for the building are given in Table 2 (Zürcher and Frank, 1998).

It was deduced that double glazing was installed in front of massive wall. For the glazing, KL multiplication was taken as 0.0125, the vertical radiation permeability of the glaze was thought to be (τ) 0.83 (Duffie and Beckman, 1991). The absorption coefficient (α) of wall elements was determined regarding the selected surface colour (Table 3) (Özışık, 1985). The effective heat storage capacity of the building was accepted as 59.35 MJ/K (Duffie and Beckman, 1991).

Meterological data

The map of Turkey and the location of Erzurum city is displayed in Figure 6 (http://www.eie.gov.tr, 2009). The climatic data of Erzurum

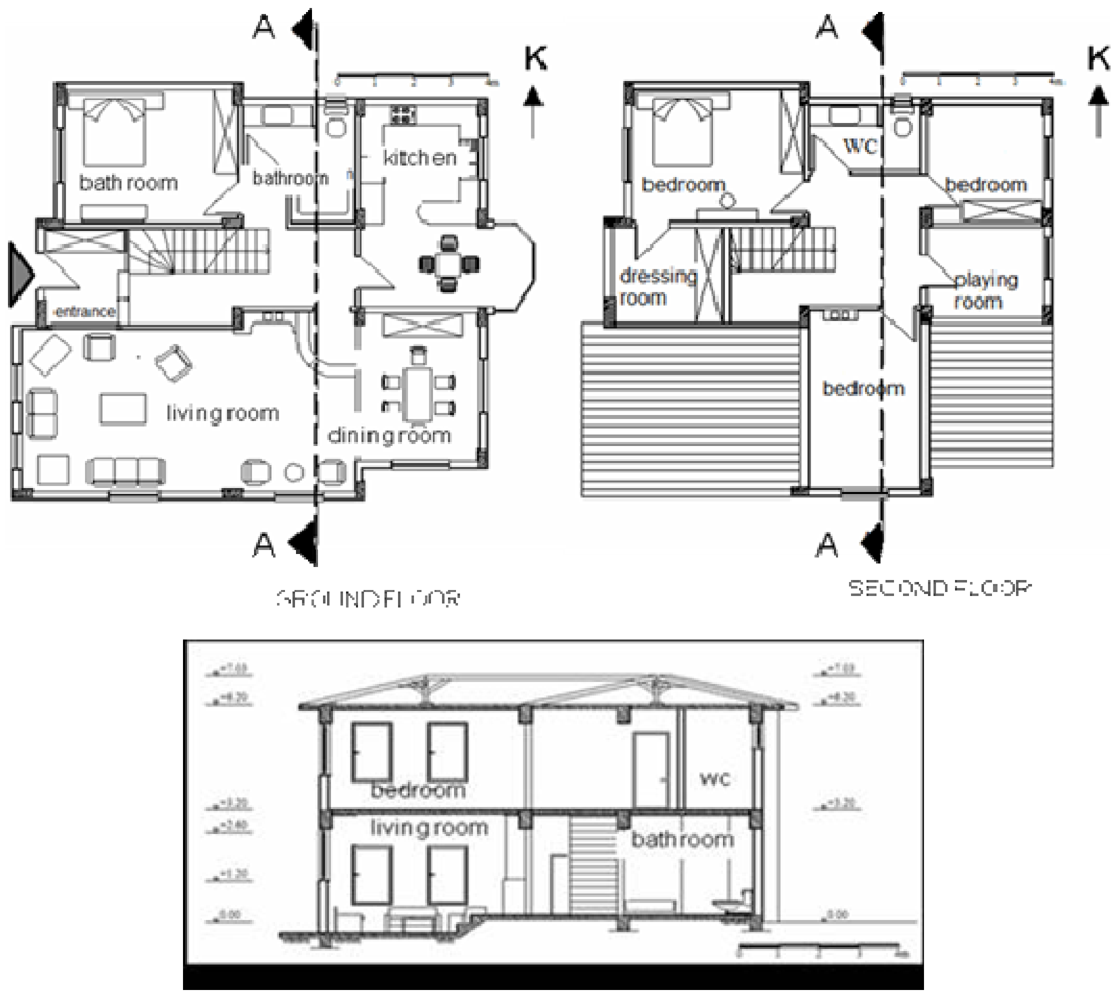

Figure 3. The plans and section of the building.

Table 1. Parameters of the building.

Area, volume measures	
Floor area(m^2)	118.7
Total volume-V_{gross} (m^3)	400.21
Total area-A_{total} (m^2)	563.3
Area/Volume ratio: A_{total}/ V_{gross} (m^{-1})	1.41
Total wall area: A_{wall} (m^2)	142.24
Total window /door area: $A_{window-door}$ (m^2)	58.51
Total roof area: A_{roof} (m^2)	156.09

is given in Figure 7. Monthly average daily solar radiation on vertical surface is ($\bar{H}$) 5.3 – 13.7MJ/m^2 day, outdoor temperature varied between -8.3 and -15.0 °C during the heating period.

RESULTS

In this study the efficiency of Trombe wall application for heat gain from solar energy in Erzurum was calculated. The annual energy requirement of the sample building was calculated by insulating it in accordance with TS 825 rules Q_{year} = 22390 kWh. In order to decrease energy consumption of the building, it was found out that solar energy gain through the 24.5 m^2 south oriented Trombe wall is about 6041, 4532, 2183 kWh/year for concrete wall; 4609, 3686, 1607 kWh/year for brick wall; and 2923,

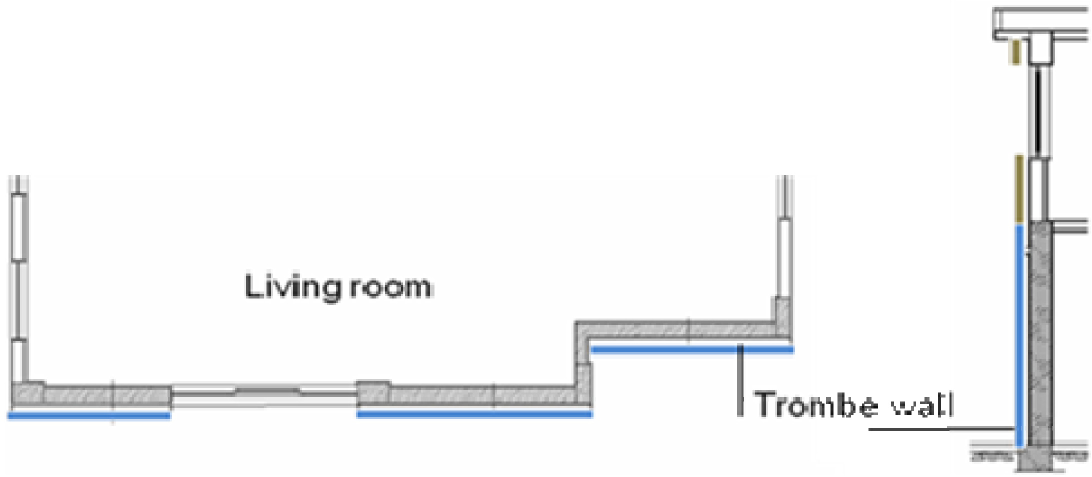

Figure 4. The schematic view of Trombe wall in plan and section.

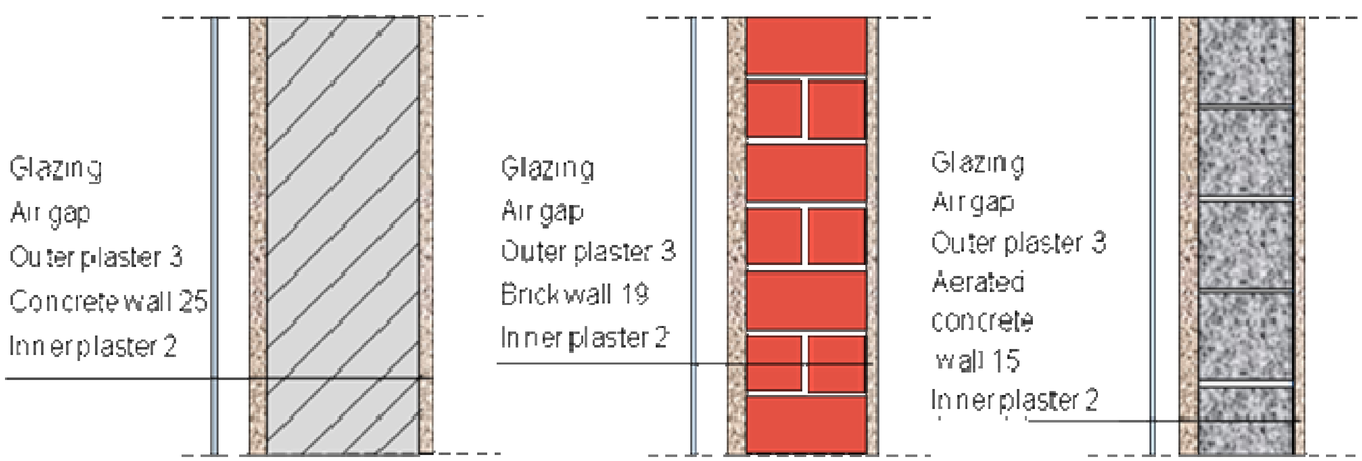

Figure 5. Investigated wall constructions with different materials.

Table 2. Thermophysical properties of building materials Zürcher and Frank (1998).

	Thickness d (m)	Thermal conductivity k (W/mK)	Density ρ (kg/m^3)	Specific heat (joule/kg°C)
Reinforced concrete	0.25	2.01	2400	1060
Brick	0.19	0.45	1100	900
Aerated concrete (AAC)	0.15	0.13	500	1000
Inner plaster	0.02	0.70	1400	900
Outer plaster	0.03	0.87	1800	1100

Table 3. The absorption coefficients of absorbing surfaces (Özışık, 1985).

	Dark coloured	Natural coloured	Light coloured
Reinforced concrete	α = 0.91	α = 0.65	α = 0.30
Brick	α = 0.91	α = 0.70	α = 0.30
AAC	α = 0.91	α = 0.55	α = 0.30

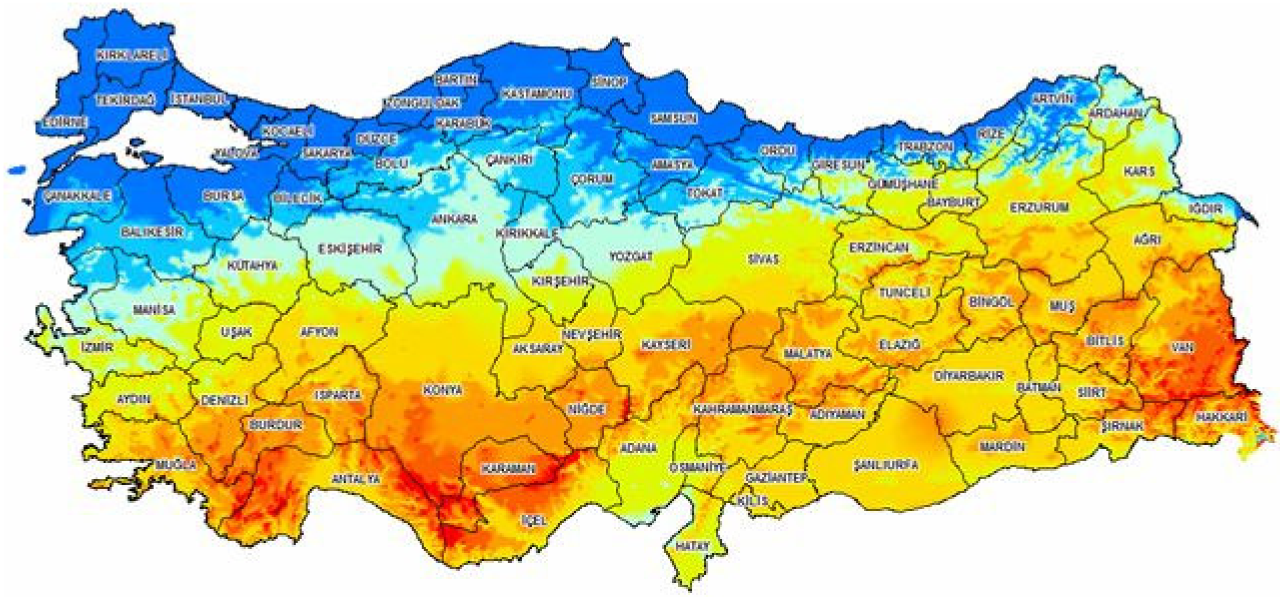

Figure 6. The solar radiation map of the Turkey and location of Erzurum (EIE, 2008).

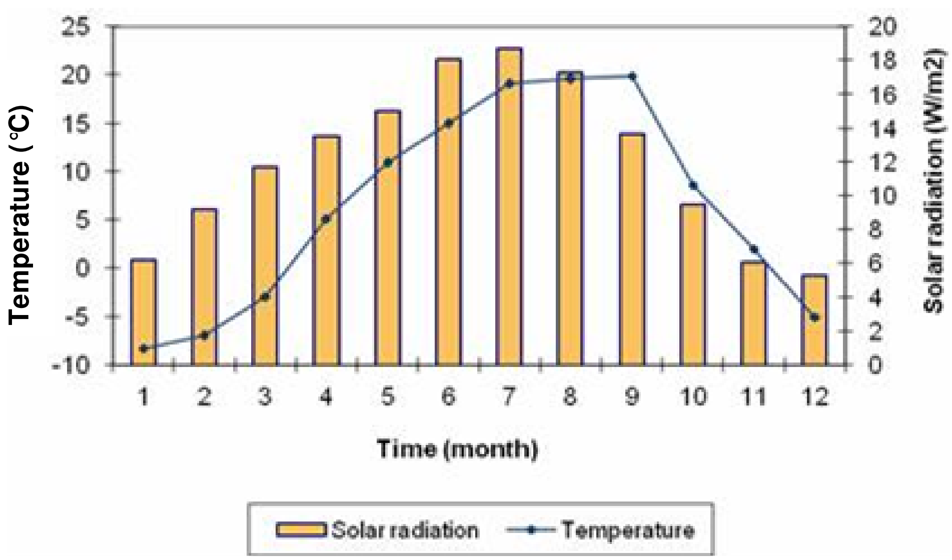

Figure 7. Outdoor temperature and montly average daily incident solar radiation on the horizontal surface for Erzurum.

1776, 976 kWh/year for aerated concrete wall with different colour intensity of wall surfaces (dark, natural, light respectively). The calculations were accomplished with UU method.

The weather data of Erzurum is given on the Table 4.

The absorbed solar radiation in the Trombe wall ($\bar{S}$) varied between 4.2 - 9.1 MJ/m^2 day. During the heating period, the solar radiation on the horizontal surface varied between 5.3 to 18.1 MJ/m^2 day.

In the study, it was determined that supporting the annual heating requirement from solar energy through the dark coloured concrete Trombe wall is about 26.9%. This ratio is 16.9% in December (the lowest rate), while in May it is about 59.03% (the highest rate). Additionally, providing the annual heating requirement from solar energy through the natural coloured concrete Trombe wall is about 20.2%. This ratio is 12.1% in December (the lowest rate), while in May it is about 42.9% (the highest rate). The annual heating requirement from solar energy

Table 4. The weather data of Erzurum.

Month	$\bar{T}$ (°C)	DD	$\bar{H}$ (MJ/m^{2}day)	$\bar{H}_d / \bar{H}$	$\bar{K}_T$	$\bar{R}_b$	$\bar{H}_T$ (MJ/m^{2}day)	$\bar{S}$ (MJ/m^2 day)
January	-8.3	846.39	6.2	0.494	0.40561	2.30679	10.99846	7.698672
February	-7.0	728.27	9.2	0.446	0.44646	1.58697	13.45894	9.107461
March	-3.0	682.24	11.7	0.504	0.42559	0.952615	12.14336	7.646691
April	5.1	418.13	13.5	0.545	0.38945	0.482591	8.574898	5.07952
May	10.9	256.58	15.0	0.559	0.37773	0.250155	7.377366	4.223922
June	15.0	136.33	18.1	0.4964	0.43337	0.171226	7.862594	4.406735
July	19.1	52.85	18.7	0.468702	0.45962	0.204348	8.282621	4.500873
August	19.6	45.13	17.3	0.455136	0.47299	0.370989	9.163923	5.188733
September	14.9	138.85	13.7	0.472681	0.45577	0.738342	9.954401	6.103425
October	8.6	325.39	9.5	0.510753	0.42017	1.356963	9.750452	6.53452
November	2.0	510.56	6.1	0.540075	0.36929	2.095422	8.426796	5.918583
December	-5.1	747.26	5.3	0.521835	0.38301	2.562089	9.47317	6.666795

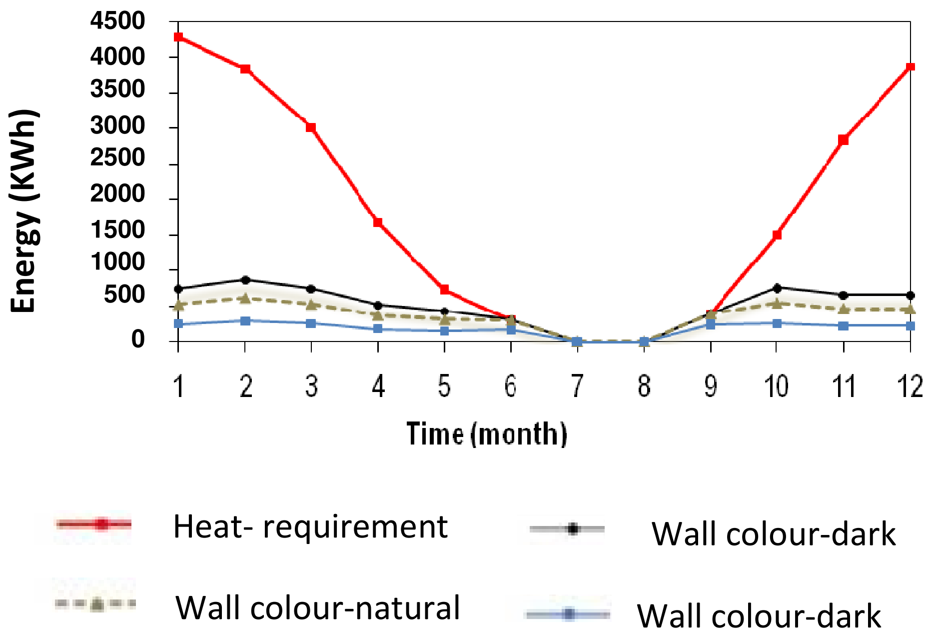

Figure 8. Monthly solar gain of concrete Trombe wall with various colour.

through the light coloured concrete Trombe wall is about 9.7%. This ratio is 5.6% in December (the lowest rate), while in September it is about 61.9% (the highest rate) (Figure 8).

It was also determined that providing the annual heating requirement from solar energy through the dark coloured brick Trombe wall is about 20.5%. This ratio is 12.2% in December (the lowest rate), while in May it is about 45.0% (the highest rate). Additionally, providing the annual heating requirement from solar energy through the natural coloured brick Trombe wall is about 16.4%. This ratio is about 9.4% in December (the lowest rate), while in June it is about 92.9% (the highest rate). The annual heating requirement from solar energy through the light coloured brick Trombe wall is about 7.1%. This ratio is 4.0% in December (the lowest rate), while in September it is about 47.3 % (the highest rate) (Figure 9).

It was determined that providing the annual heating requirement from solar energy through the dark coloured AAC Trombe wall is about 13.0%. This ratio is 7.3% in December (the lowest rate), while in September it is about 85.9% (the highest rate). Additionally, providing the annual heating requirement from solar energy through

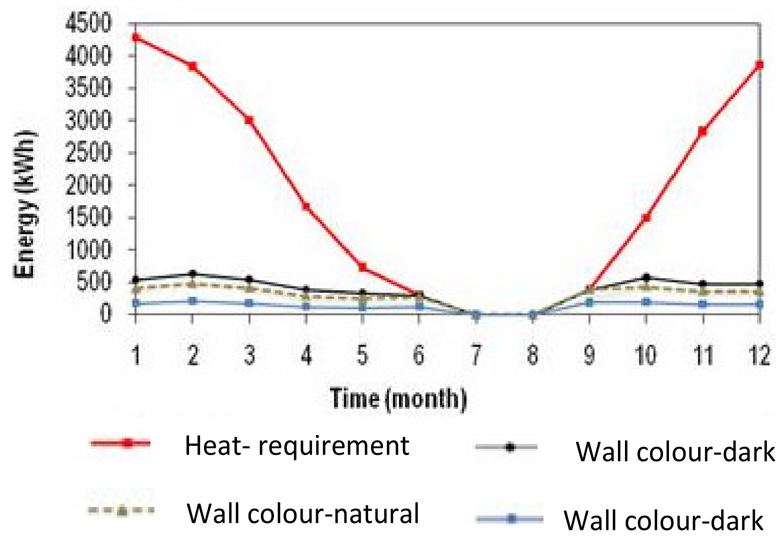

Figure 9. Monthly solar gain of brick Trombe wall with various colour.

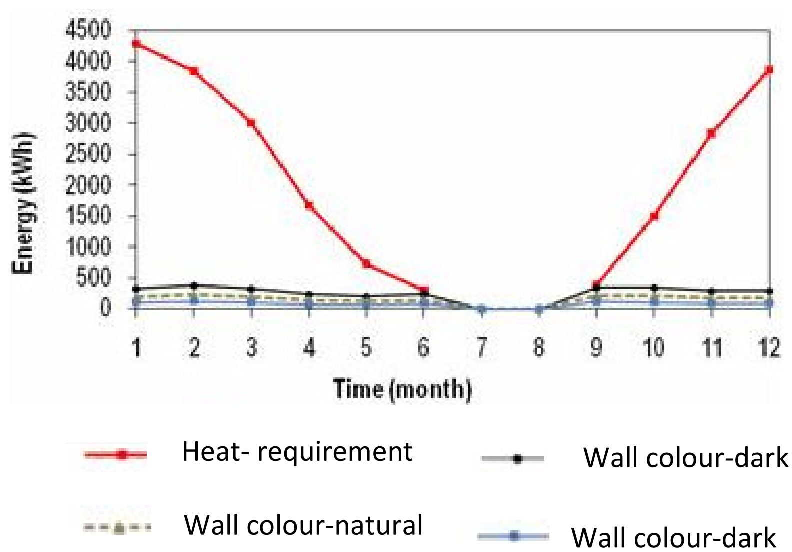

Figure 10. Monthly solar gain of aerated concrete Trombe wall with various colour.

the natural coloured AAC Trombe wall is about 7.9%. This ratio is 4.4 % in December (the lowest rate), while in September it is about 53.2% (the highest rate). The annual heating requirement from solar energy through the light coloured AAC Trombe wall is about 4.3%. This ratio is 2.4% in December (the lowest rate), while in September it is about 29.8% (the highest rate) (Figure 10).

As a result of this work, it indicated that annual heat gain through solar energy on dark, natural and light coloured concrete Trombe walls in Erzurum was found out to be 26.9, 20.2 and 9.7% respectively; on brick Trombe wall, it was calculated as 20.5, 16.4 and 7.1% respectively, while on autoclaved aerated concrete wall it was determined to be 13.0, 7.9 and 4.3%. The results proved that the varied absorption coefficient depending on the colour of outer surface affects the solar energy gain. (Table 5)

DISCUSSION

Performance level of Trombe wall depends on the heat storage capacity and heat diffusion coefficient of wall material. The thermal capacity of wall is related with specific heat and mass of wall material and thus, with

Table 5. Annual heat gain from solar energy through Trombe wall.

Surface colour	Annual heat gain from solar energy through Trombe wall with various materials (%)		
	Reinforced concrete	Brick	AAC
Dark	26.9	20.5	13.0
Natural	20.2	16.4	7.9
Light	9.7	7.1	4.3

density and total volume. The efficiency of wall element absorbing heat is related to absorption of energy and transmission rate (speed) of this energy into indoor. The materials of which heat storage capacity is highly absorbed large amount of energy. Thus, they transmit some part of the stored energy to the other surfaces depending on their thermophysical properties such as density, thickness, specific heat and heat conductivity coefficient. In addition, higher coefficient of heat conductivity means the transmitted energy is more than the stored energy.

The heat storage capacity on the concrete wall was at the highest level. The heat transmit coefficient of AAC wall was at the lowest level when compared with other types of walls examined in this study. Moreover, since the heat storage capacity of AAC wall was lower, both the absorption speed and transmittance of the heat into indoor were lower than the brick and concrete walls (Kartal, 2009). Since the speed of energy absorption and transmittance of it into indoor of concrete and brick walls were higher, heat gain was higher respectively. Heat diffusion coefficient had the highest value in concrete wall. The highest ratio of heat diffusion coefficient caused to the highest ratio of transferred energy than stored energy.

The change in absorption coefficient depending on outer surface colour affected heat gain from solar energy. Absorption coefficient got gradually decreased from 0.91 (dark colour) to 0.65 (natural colour) and to 0.30 (light colour). In consequence of such decrease, the ratios of net reference heat load from solar energy got decreased on natural and light coloured surfaces when compared to dark coloured surface (Özışık, 1985).

In addition, using renewable energy reduces CO_2 emissions released into the atmosphere. Thus, it was concluded that energy gain for heating through solar energy is worth mentioning in the regions which are cold but has high solar radiation.

Conclusion

Trombe wall application needs to be taken into account inevitably for the design of buildings in order to provide energy gain from renewable sources such as solar energy for the environment and sustainability. The Trombe walls provide significant heating to the buildings without paying energy cost.

NOMENCLATURE

A_r, Trombe wall-area m^2 ; DD,degree day; f, monthly solar fraction; fi, solar fractions corresponding for infinite thermal capacitance; f_z, solar fractions corresponding for infinite thermal capacitanc $\bar{H}$, monthly average total solar radiation (MJ/m^{2}day); $\bar{H}_b$, monthly average beam component of the solar radiation(MJ/m^2), $\bar{H}_d$ Monthly average diffuse component of solar radiation(MJ/m^2); $\bar{H}_T$, monthly average daily radiation on tilted surface (MJ/m^{2}day); I_T, hourly total radiation on tilted surface (MJ/m^{2}h) ; I_{TC}, hourly critical radiation on tilted surface (MJ/m^{2}h); L, Total thermal load of the building (GJ) Lad, the heat load of the building, except Trombe wall (GJ). L_{Ai}, monthly energy balance for infinite thermal capacitance (GJ); L_{Az}, monthly energy balance for zero thermal capacitance (GJ); N, number of days in month; S, Heat storage capacity (W s½/m^{2}K); $\bar{S}$, monthly average absorbed solar radiation on tilted surface(MJ/m^2); T_b , Base temperature (K, °C);T_d, Exterior temperature (K, °C) T_i, interior temperature (K, °C) T_w Surface temperature (K, °C) UOverall heat transfer coefficient (W/m^{2}K) Q_n, Net monthly heat transfer to the building (GJ); Q_D, dump energy (GJ) X, Solar load ratio; ρ_g, ground reflectance, β, The angle of the surface; $(\bar{\tau\alpha})_d$ monthly average transmittance-absorptance multi-plication for diffused radiation $(\bar{\tau\alpha})_g$, monthly average transmittance-absorptance multiplication for ground- reflected radiation; $\bar{\phi}$, monthly average daily utilizability; Y, dimensionless absorbed energy ratio

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