

Effects of Airtightness and Solar Heat Gain Coefficient (SHGC) on Heating Energy Performance of Building Envelope with Trombe Wall

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ABSTRACT

This study models the retrofit of a Trombe wall to the southern façade of an existing dwelling in Edirne, Turkey. The existing (uninsulated) heating load of the building is calculated as 88 kWh/m². After the application of insulation, annual heating load decreased to 30 kWh/m². In addition, annual heating load of the building was calculated as 27 kWh/m² when a Trombe wall was applied to the southern façade. The study assesses the effects of changes to the building envelope in terms of airtightness and solar heat gain coefficient (SHGC), which influence annual heating load. The effects are calculated according to two scenarios, using Energy Plus and Design Builder software. The two scenarios show 15% and 23% reductions in heating load, respectively, associated with an improvement in airtightness from 1.0 ac/h to 0.7 ac/h and 0.5 ac/h, respectively. An increase from 0.5 to 0.7 in SHGC results in decreases of 4% and 13% respectively in terms of heating load. The findings suggest a Trombe wall represents a practical option for improving energy efficiency by reducing heating load.

Keywords: Trombe wall, SHGC, Airtightness, heating load

1. INTRODUCTION

The construction sector accounts for large proportions of overall energy consumption in Turkey [1]. Heating accounts for up to 85% of energy used in structures [2]. Inadequate thermal insulation is one of the primary reasons for the high energy consumption of the current building stock in Turkey. The first step in constructing energy-efficient and sustainable buildings is to ensure that the building envelope is highly insulated. The visual and thermophysical properties of the building envelope play important roles in the amount of energy gained or lost (considering the impact of outdoor air temperature and solar radiation) per unit area of the building envelope [3]. The building envelope protects users from external climatic factors like hot/cold weather and wind, functions as a filter between interior and exterior space, and is an important element of the energy performance of a building. The main purposes when designing a building envelope are to ensure the maximum utilization of sunlight, improve indoor air quality, and provide conditions that meet users' expectations of privacy and visual quality [4]. In this respect, airtightness and solar heat gain coefficient (SHGC) are important parameters for the heating energy performance of the building envelope.

As a parameter of the heating performance of the building, problems related to airtightness can be due to windows or inferior quality of workmanship. Air outflow from gaps between windows and walls due to inferior workmanship can be remedied by means of various materials and techniques. Proskiw [5] and Relander *et al.* [6] offered different techniques and materials to eliminate air outflows. Van Den Bossche *et al.* [7,8] compared various solutions for ensuring the airtightness of the window-wall interface. Continuation of the airtight plane from the plaster to the window frame via an air seal can be achieved by membranes, sprayed foam, gaskets, and sealant joints. The authors concluded that the use of a plywood frame around the window unit was highly airtight (0.03 m³/h.m at 50 Pa) and incorporates considerable redundancy. In a moderate climate such as that in Belgium, infiltration of cold air accounts for up to 20% of overall energy loss for code-compliant buildings [7,8]. In general, the existing housing stock in colder climates is more airtight than that in moderate climates [9]. In addition to the influence of the materials used in the building envelope, high quality of workmanship is necessary to ensure airtightness. Therefore, even if the design of the building envelope is energy efficient, poor quality workmanship can result in a significant reduction in airtightness.

SHGC is the ratio of solar heat gain through glass relative to the incident solar radiation on the glazing. SHGC includes both the solar energy directly transmitted through the glazing, and that absorbed by the glazing and subsequently convected and radiated inward [10]. SHGC permits sensitive evaluation of the thermal performance of window units in terms of solar control against solar radiation or heat gain. It represents solar heat gain via windows, comprising the total thermal energy that permeates into the inner space through the glazing, and the thermal energy

that is already absorbed by the framework and glass [11]. Transparent elements with high SHGC should be used to improve the energy efficiency of a building. In such buildings, the problem of overheating in summer can be addressed by incorporating elements such as sunblinds, balconies, and eaves. Luther *et al* [12] developed easily accessible Microsoft Excel programs to highlight the significance of the orientation-based heat transfer calculation using climate and SHGC (WINDOW-6) data.

The design of energy-efficient buildings requires an approach that aims to minimize environmental damage throughout the entire process of planning, construction, use, and transformation of the structure. An energy-efficient building is defined as a structure that requires the minimum amount of energy; acquires the energy it needs from clean, renewable resources; and achieves minimum emissions of CO₂, SO₂, and other greenhouse gases [13]. In this respect, integrating a Trombe wall within the building envelope can contribute to the construction of energy-efficient buildings.

2. INFLUENCE OF AIRTIGHTNESS AND SHGC ON HEATING LOAD OF A HOUSE WITH TROMBE WALLS

A Trombe wall is a glass façade that is integrated into a building envelope for passive utilization of solar gain. The glass outer façade is separated by an air barrier from an inner gravity (retaining) wall of high heat capacity. The façade admits solar radiation, creating a greenhouse effect within the inner space; the energy is absorbed by the dark-colored wall and re-radiated rather than passing back through the glass, thereby heating the inside of the building. In this system, the thermal qualities of the mass wall, its thickness, surface color, surface area, and orientation are important parameters. The Trombe wall will be oriented southward, and the interior mass wall will be painted a dark color. Solar radiation that passes through the transparent façade is trapped between the glass and the wall, and re-transmitted to interior space via channels located on the upper and lower sections of the mass wall (Figure 1). It is also possible to locate water-filled pipes, tubes, or barrels behind the glass in place of a gravity wall. In order to avoid overheating during summer, sunblinds or plants may be installed to provide shading. In addition, the air channels on the upper section of the transparent surface allow rising hot air to be ventilated to the exterior. The effects of airtightness and SHGC on the operation of a Trombe wall façade system are calculated with reference to the climatic conditions of Edirne, Turkey, using Energy Plus software [14].

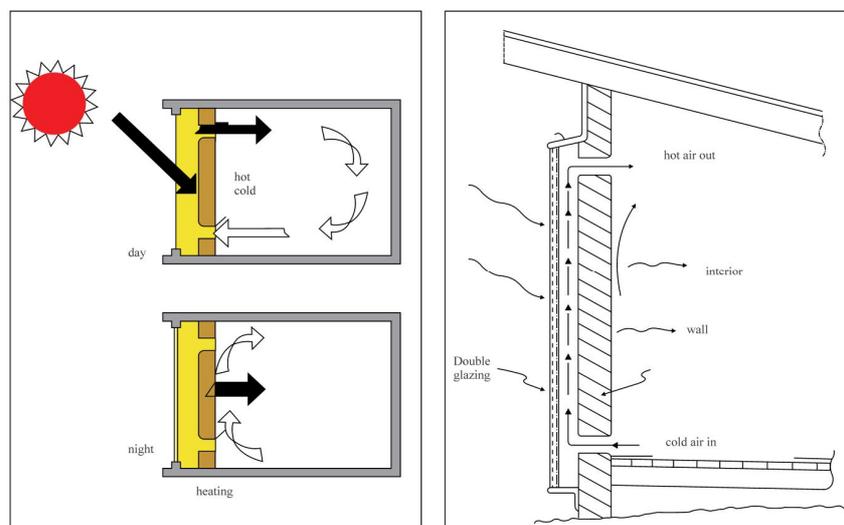


Figure 1 Function of a Trombe wall [15]

2.1 Method—Energy Plus

Many types of software are used to simulate the physical and environmental performance of buildings. These programs have differing evaluation criteria and are selected for specific purposes. In this study, the energy performance of an existing building is compared with its projected performance after specific changes are made to enhance energy gain. Energy Plus software provides dynamic simulation of the energy consumption associated with heating, cooling, and ventilation in an existing building or one that is in project phase [14]. The software simulates interactions between changing temperature and humidity rate, and the thermophysical properties of the given building. As an interface for Energy Plus, the present study used Design Builder software, which was chosen for its practical interface, ability to process large data sets, and ease of model development. In this study, airtightness and SHGC are assessed in separate scenarios in terms of the heating energy performance of the existing building envelope with the addition of a south-facing Trombe wall.

2.2 Parameters Related to Dwelling with Trombe Walls

The building structure that is taken as a model for this study is a three-story reinforced concrete dwelling with carcass system. The floor area of the dwelling is 120.60 m² and the total floor area of the three stories is 371.40 m². Data on the structure are given in Tables 1 and 2 and Figures 2 and 3, [15].

Table 1: Areal and volumetric data for the building [15]

Areal and Volumetric Data	
Floor space (m ²)	120.60
Total volume: V _{gross} (m ³)	1039.92
Total area: A _{top} (m ²)	371.40
Area/Volume ratio: A _{tot} /V _{gross} (m ⁻¹)	2.8
Total wall area: A _{wall} (m ²)	294.156
Total window + Door area: A _{window/door} (m ²)	63.16
Total roof area: A _{roof} (m ²)	125.40

Table 2: Properties of building elements [15]

Building Elements	Width (m)	Heat conductivity value: k (W/mK)
Brick - horizontal perforated (wall)	0.19	0.45
Concrete elements (pillar, joist)	0.25/0.5/0.6/0.7	2.1
Interior building elements		U-value (W/m ² K)
Window: Plastic-framed double glazing		2.3
Door: Plastic-framed double glazing		2.3

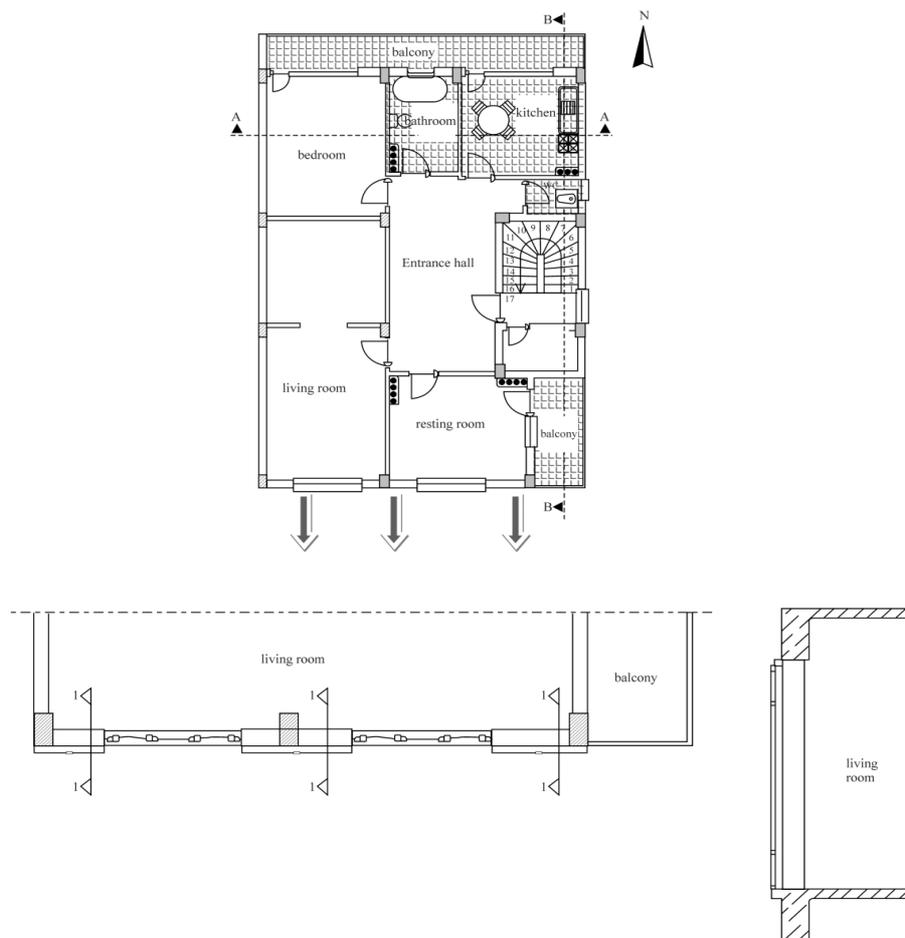


Figure 2 Plan and cross-section of the dwelling [15]

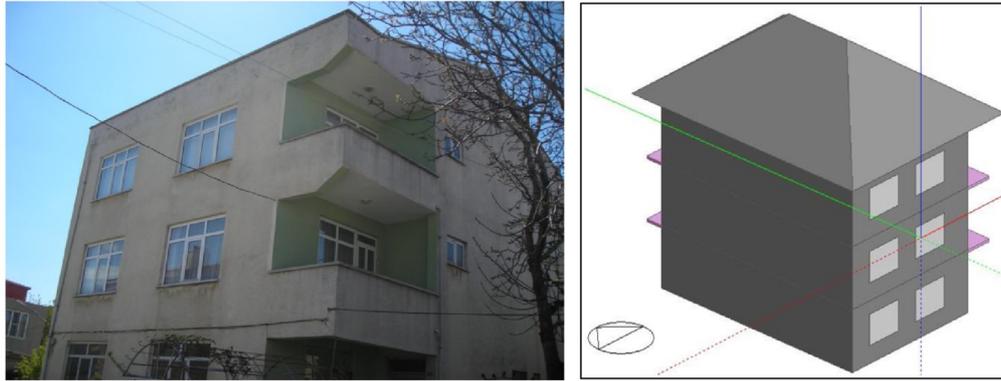


Figure 3 Photograph and model of the dwelling [15]

2.3 Regional Climate

Edirne is located in a moderate–humid climatic region of Turkey, and has short sunshine duration and low annual solar energy potential of 1400–1450 kWh/ m² (Figure 4) [16]. Weather conditions are hot and arid in summer, while winter is cold and wet. Annual average temperature is 13.8 °C, and the coldest and hottest months are January and July respectively [16]. Annual average rainfall is 620.5 mm; lowest rainfall occurs in summer, during which average humidity is 77.5%. Average wind velocity is 2.6 m/sec.

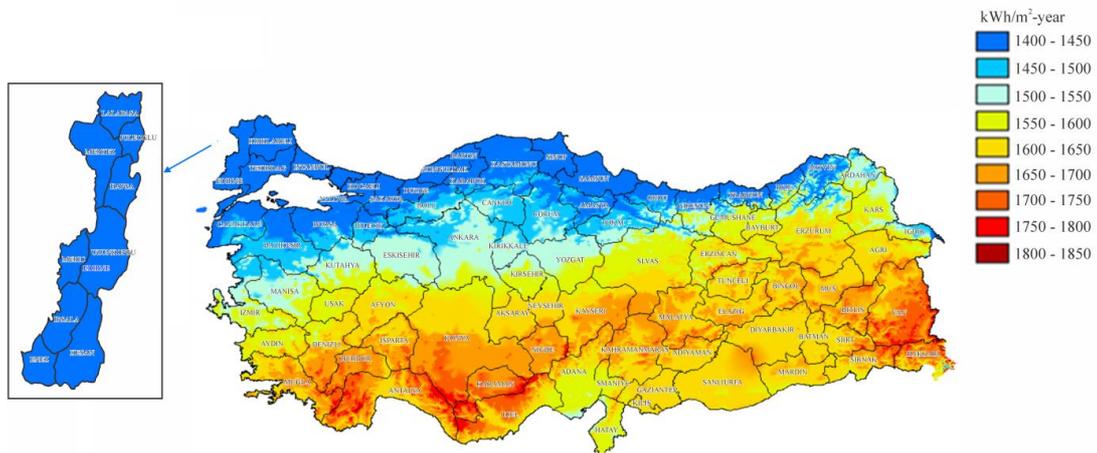


Figure 4 Solar map of Turkey and Edirne [16]

3. FINDINGS

The existing (uninsulated) annual heating load of the building was calculated as 88 kWh/m², (Figure 5) which decreased to 30 kWh/m² after the application of insulation. In addition, annual heating load of the building is calculated as 27 kWh/m² with the installation of a Trombe wall to the southern façade.

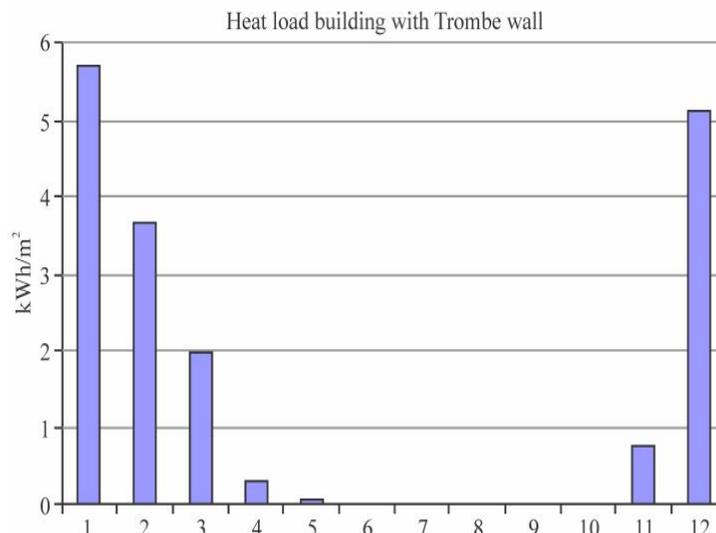


Figure 5 Monthly variation in building heating load with Trombe wall [15]

3.1 Scenario 1: Changes in Annual Heating Load with Trombe Walls with Respect to Airtightness

In the first scenario, heating loads are calculated for three different airtightness for the southern façade to which the Trombe wall is attached. The effects of changes in airtightness on heating load are shown in Figure 6. Annual heating loads for airtightness levels of 1.0, 0.7, and 0.5 ac/h are calculated as 27 kWh/m², 23 kWh/m², and 18 kWh/m², respectively.

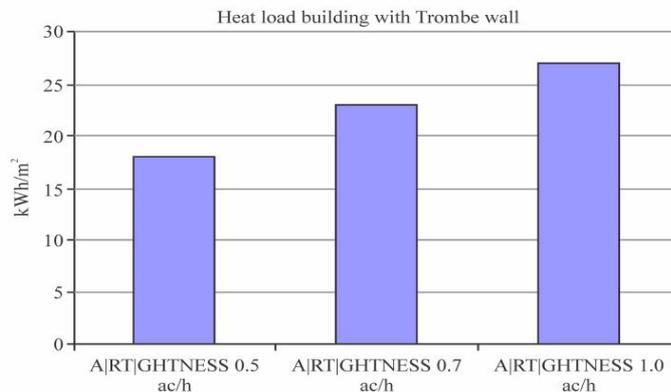


Figure 6 Annual heating load with Trombe wall with respect to building airtightness [15]

The simulation predicts that heating load would decrease by 23% with greater airtightness. The level of airtightness, which reflects the quality of workmanship, is an important parameter of heating load and directly influences the energy performance of a building. High quality of workmanship will increase airtightness, resulting in less energy loss and therefore lower energy consumption [18]. Heating load increases with decreasing quality of airtightness (from 0 to 1)

3.2 Scenario 2: Changes in annual heating load with Trombe walls with respect to solar heat gain

In the second scenario, heating loads are calculated for three different SHGCs for the southern façade to which the Trombe wall is attached. For SHGCs of 0.5, 0.6, and 0.7, estimated annual heating loads are 31 kWh/m², 30 kWh/m² and 27 kWh/m², respectively (Figure 7). SHGC values are between 0 and 1, with higher value indicating greater solar input. The degree of utilization of sunlight increases with increasing SHGC value towards 1 and declines with decreasing SHGC value towards 0.

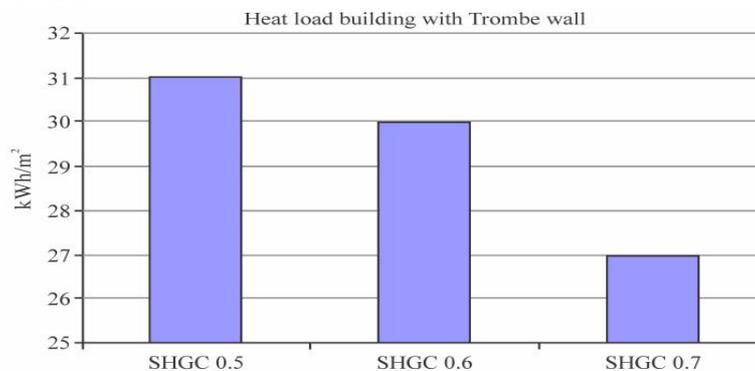


Figure 7 Changes in annual heating load of building with Trombe walls with respect to solar heat gain [15]

4. CONCLUSION

The ongoing depletion of fossil fuels, increasing pollution and demand for energy, and growing energy-dependency of some countries necessitates reducing the energy consumption of buildings. Heating accounts for the largest proportion of energy consumed by buildings [17]. Therefore, it is important to investigate energy efficiency measures during the design process in order to reduce the use of energy for heating. In order to achieve that, it is important to determine the influence of the parameters of heating load [18]. In addition to passive architectural solutions for reducing energy consumption, such as the application of Trombe walls to the building envelope, the influence of airtightness and SHGC should be evaluated. The simulation showed that, after retrofitting a Trombe wall, increased SHGC from 0.5 to 0.7 was associated with decreases of 4% and 13% respectively in heating load. Increased airtightness, from 1.0 ac/h to 0.7 ac/h and 0.5 ac/h, was associated with decreases of 15%, 20%, and 23%, respectively, in heating load. The findings suggest that a Trombe wall is a practical option for improving the energy efficiency of the model building, and contributes considerably to reducing the heating load. SHGC is related to transparent building elements, and it was observed that a transparent element with higher coefficient reduces the annual heating load of the dwelling. Furthermore, greater airtightness, which depends on the material choice and quality of workmanship, can also reduce heating load.

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