Energy-efficient house design in the mediterranean climate

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Abstract. Buildings in rural areas are more exposed to open weather conditions than city centres and, therefore, need to be designed to be more energy efficient. This study systematically investigates the sensitivity of critical building design parameters (building orientation, insulation thickness, glazing properties, shading, and ventilation type) on the heating and cooling energy demand of a rural building in a Mediterranean climate. This study also aims to determine optimum energy-efficient building design conditions in the Mediterranean climate. Thermal simulations were performed using the IESVE tool in a typical two-storey Mediterranean house designed in rural İzmir, Turkey. It was found that critical design parameters such as solar orientation, insulation thickness, glazing properties, shading, and ventilation type affect heating and cooling energy demand. Orientation of the building to the South, 23.5 cm insulation thickness, triple glazing windows, and shading provide maximum energy savings. In addition, South orientation or a deviation of 22.5° from the South, 15 cm insulation thickness, double-glazed windows, and shading ensure significant energy savings and acceptable energy performance in the Mediterranean climate. However, no significant difference in energy performance was found depending on ventilation type (mechanical or mixed mode (natural + mechanical)). The results of this study can promote energy-efficient building design at the local level and help architects design new energy-efficient buildings in the Mediterranean countryside. This study can also contribute to creating energy-efficient building design policies to reduce buildings' dependence on fossil fuels.

1 Introduction

The building construction sector accounts for 37% of global CO2 emissions and 36% of global energy consumption as of 2021[1] and this rate is expected to exceed 50% by 2050 [2]. Approximately 50-60% of the energy in buildings is used mainly for space cooling, heating and ventilation needs [3, 4]. Therefore, reducing space heating and cooling energy use in buildings is one of the most important issues in reducing global energy consumption. More specifically, in Turkey, buildings account for 20% of the country's total energy use [5]. Decision-makers aim to reduce Turkey's energy consumption by 20% compared to 2011 levels by 2023 [5]. Therefore, they promote energy-efficient building construction policies for new buildings. Especially buildings in rural areas are exposed to more open weather conditions than in city centres, and therefore they need to be designed more energy efficient.

In improving energy efficiency in buildings, it is necessary to investigate critical building design parameters and the thermal/physical properties of materials that affect the energy performance of the building. The first step in energy-efficient home design is orientation to the sun. In some situations, South orientation of buildings in the Northern Hemisphere may not be possible. For this reason, it should be known how much deviation from the South will change the solar energy gain.

A well-insulated external building envelope can minimize heat losses and reduce heating and cooling energy demand. Glazing selection is critical in window design since glazing acts as a solar energy collection system. Choosing suitable glazing compatible with climate characteristics can significantly reduce the heating and cooling load.

Appropriate shading devices can prevent overheating in summer in the Mediterranean climate, as they block unwanted solar energy and also reduce the cooling load of the building. However, fixed shading devices are only suitable for some seasons as they are not flexible depending on the sun's altitude. Therefore, there is a need for seasonably operable shading devices which can adapt to environmental conditions, such as horizontal and vertical sun angles that constantly change in seasonal cycles. On the other hand, heat losses and gains due to ventilation affect the heating and cooling load. For this reason, the effect of ventilation types (mechanical or mixed mode (natural + mechanical)) on heating and cooling loads becomes important.

Based on the above discussion, the objective of this study is to understand the sensitivity of building orientation, insulation thickness, glazing properties, shading and ventilation type (mechanical or mechanical + natural) on heating and cooling energy demand and determine the optimum energy-efficient design conditions in rural buildings exposed to open weather conditions in the Mediterranean climate. This study also aims to promote energy-efficient building design at the

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local level and to be a good source for town architects interested in energy efficiency in building design.

2 Method

The method of this hypothetical study is based on simulations. Thermal simulations were performed using the IESVE environmental simulation tool in a typical two-storey Mediterranean house designed in rural İzmir. IESVE was tested and validated according to BESTEST (Building Energy Simulation Test), an internationally recognized procedure [6].

2.1 Description of the basic operating model

As a basic operating model, a simple building for a family of five was hypothetically designed. The two-storey building is 10 m wide, 7.5 m deep and 6 m high. The glazed areas on the South and East facades are 11.5 m^2, 7.5 m^2, respectively and North and West facades are 3 m^2. Infiltration heat loss is 0.25 ac/h, and ventilation heat loss is 10 l/s per person [7]. Heating and cooling set temperatures were applied at 21 °C and 24 °C, respectively. No external obstacles and internal gains are taken into account. Figure 1 shows the building's South, East, North and West views obtained from IESVE. Unless stated otherwise, as the default mode, simulations were performed using double-glazed windows with a U-value of 2.8 $Wm^{-2}K^{-1}$ and 6 cm XPS insulation applied on 20 cm brick walls, mechanical ventilation and no shading device.

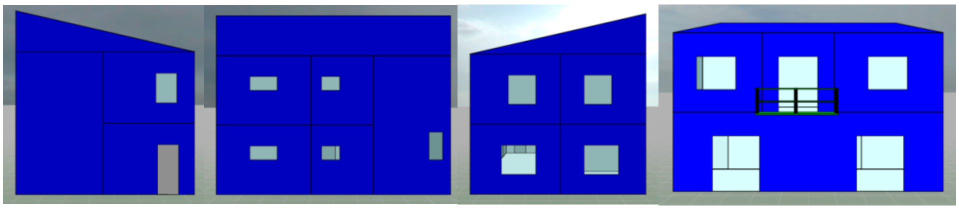

Fig. 1. South, East, North and West views of the building obtained from IESVE.

2.2 Climatic conditions

İzmir is located at 38.25 °N latitude and 27.09 °E longitude. The city shows the characteristic features of the typical Mediterranean climate, labelled CSa in the Köppen climate classification. The warmest month is July, with an average maximum temperature of 33.2 °C, and the coldest month is January, with an average minimum temperature of 5.9 °C. İzmir's climate shows that both the heating and cooling performance of buildings are necessary. The actual climatic data of İzmir for simulations are automatically established in IESVE.

3 Simulations for calculating annual space-heating and cooling energy use

The effect of orientation, insulation thickness, glazing properties, shading, and ventilation type on annual space heating and cooling requirements was investigated in each case, respectively.

3.1 Effect of orientation on energy use

The effect of the orientation of buildings on the annual solar energy gain was tested by creating five different building orientations with varying angles of deviation from the South: 0° deviation (South), 22.5° deviation (South-East and South-West) and 45° deviation (South-East and South-West).

Simulations show that the most efficient direction for collecting solar energy during winter months is the South orientation. When the model is rotated 22.5° and 45° to the East, 8% and 25% of the solar gain is lost, respectively. When the model is rotated 22.5° and 45° to the West, 5% and 19% of the solar gain is lost, respectively. This means positioning buildings on the long axis (East-West) maximizes solar energy gain. In some cases, orientation to the South may not be possible due to the urban fabric's orientation and the built environment's shading. If South orientation is not possible, orientation of 22.5° to the East and West from the South was found beneficial compared to 45° deviation from the South.

3.2 Effect of insulation thickness on energy use

The effect of insulation thicknesses on heating and cooling load was investigated. Table 1 shows three different insulation thicknesses applied to a 20 cm brick wall and the U-values obtained.

Table 1. Insulation thickness.

Building Construction	Insulation (XPS) thickness	U-value ($Wm^{-2}K^{-1}$)
Brick wall 20 cm	23.5 cm	0.10
Brick wall 20 cm	15.0 cm	0.16
Brick wall 20 cm	6.0 cm	0.36

Figure 2 shows that thicker insulation significantly reduces the heating load. Increasing the insulation thickness from 6 cm to 15 cm reduces the heating load by 37%, while decreasing the insulation thickness from 15 cm to 23.5 cm reduces the heating load by 36%. 6 cm insulation, which is primarily preferred in buildings in Turkey, is insufficient to reduce the heating load significantly. The Figure 2 also shows that the insulation thickness has a negligible effect on the cooling load because the windows of the buildings are not shaded.

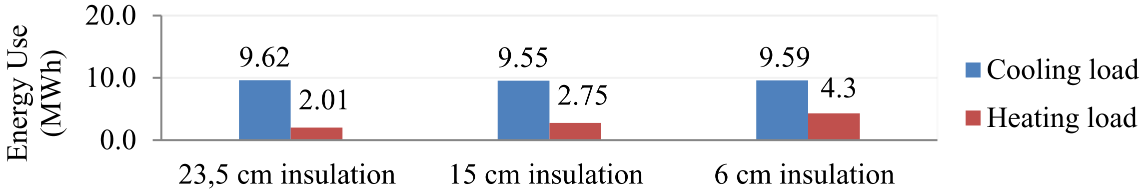

Fig. 2. The heating and cooling load of the models.

3.3 Effect of glazing properties on energy use

The effect of the physical properties of glazing on heating and cooling load was investigated. Table 2 shows the glazing properties consisting of gas filling, solar heat gain coefficient (SHGC), and U-value.

Table 2. Glazing types.

Glazing Type	Gas Fill	SHGC (solar heat gain coefficient)	U ($Wm^{-2}K^{-1}$)
Single	-	0.83	5.40
Double glazed unit (DGU) 4/25/4	Air	0.77	2.8
Triple glazed unit 4/12/4/12/4	Krypton	0.50	0.49

Figure 3 shows that although single-glazed windows collect the highest solar energy due to their high SHGC, they quickly lose the accumulated solar energy, causing the highest heating load. They also cause a more significant cooling load in the summer months. With double-glazed windows, the heating load is reduced by approximately 33% and the cooling load by 4.8%. With triple-glazed windows, the heating load is reduced by almost 43% and the cooling load by 27.5%.

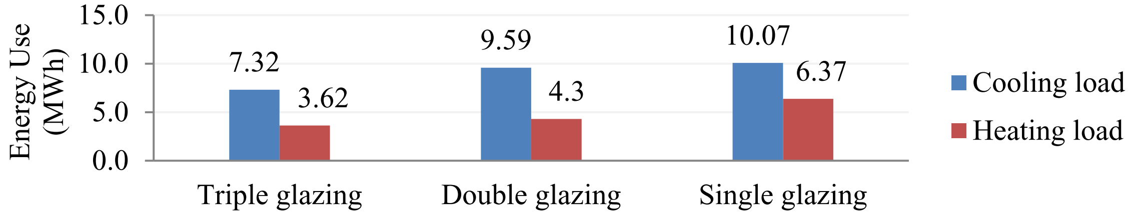

Fig. 3. Heating and cooling load by glazing type.

3.4 Shading

The effect of shading devices on heating and cooling load was investigated. A building in Mediterranean climate needs solar energy gain in winter and solar protection in summer. Yet, shading the entire building from the sun while maximizing solar access over a daily and seasonal cycle can be challenging. Therefore, an adjustable and mobile shading system was used to maximize sun access in winter and sun protection in summer. Figure 4 shows that a shading system reduces the cooling load by 50% in double and triple glazing and 56% in single glazing.

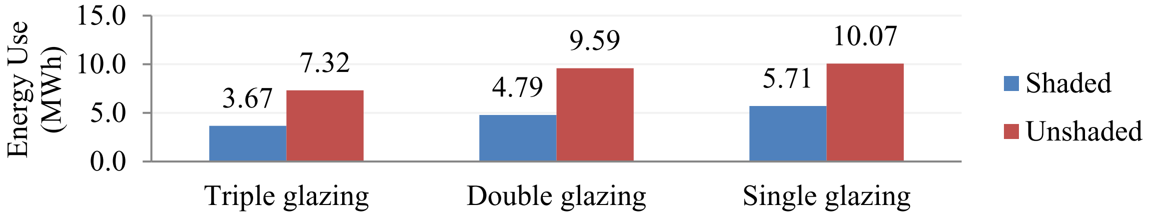

Fig. 4. Cooling load by shading device use.

3.5 Ventilation type

The effect of ventilation types (mechanical or mixed mode (natural + mechanical)) on heating and cooling load was investigated. Figure 5 shows that mixed-mode ventilation uses 0.34 MWh less energy for cooling than mechanical ventilation, meaning that natural ventilation in İzmir works for a short time during the summer months. But in winter, mixed-mode ventilation consumes 0.014 MWh more energy, a negligible amount of the total energy consumption for heating. The performance of natural ventilation can be sensitive to the orientation of the simulated building depending on wind direction. Simulations were performed under south orientation only. Therefore, it should be noted that the results may differ to some extent depending on orientation.

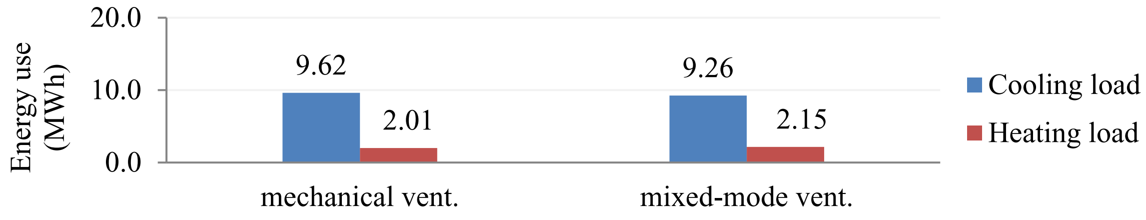

Fig. 5. Heating and cooling load by ventilation type.

4 Conclusion

Ensuring energy efficiency in buildings is critical in reducing global CO_2 emissions. This study reveals critical principles in designing an energy-efficient house in rural İzmir to promote energy-efficient buildings locally. Three key findings should be emphasized:

- The critical design parameters (building orientation, insulation thickness, glazing properties, shading and ventilation type) considerably affect space heating and cooling energy demand.
- Orientation of the building to the South, thicker insulation, triple glazing windows and shading provide maximum energy savings. However, South orientation or a deviation of 22.5° from the South, 15 cm insulation thickness, double-glazed windows and shading also ensure significant energy savings and acceptable energy performance in the Mediterranean climate.
- Mechanical ventilation supported by natural ventilation does not provide significant energy savings compared to mechanical ventilation in the Mediterranean climate.

The findings can promote energy-efficient building design at the local level and help architects design new energy-efficient buildings in the Mediterranean climate. This study can also contribute to creating energy-efficient building design policies to reduce buildings' dependence on fossil fuels.

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