

Chapter 7

Effect of Building Envelope and Environmental Variables on Building Energy Performance: Case of a Residential Building in Mediterranean Climate



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Abstract At least 30% of the World's energy consumption and greenhouse gas emissions originate from buildings. Thus, design decisions should be well studied during the design phase of buildings following energy efficiency approaches. Environmental variables and properties of the building envelope are significant for energy efficiency. Thus, this study aims to investigate the potential of a residential building in the Mediterranean climate of İzmir, Turkey, regarding decreasing energy use and understanding the significance of architectural decisions during the design stage of buildings. Eight design scenarios were created by defining seven variables affecting energy consumption for room electricity, heating, and cooling. The first three scenarios focused on environmental-related variables, i.e., surrounding buildings, ground surface materials, and building orientation, while the last five scenarios investigated building envelope-related variables, i.e., thermal transmittance of the wall, floor and roof, glass, window frame, and door types, shading elements, and natural ventilation. Then, energy modeling and simulation are applied to test their potential for minimizing energy consumption. Research findings proposed that early architectural design decisions significantly influenced the case building's energy performance. Thermal transmittance of the building components provided an annual energy saving of 22.4%, thus, was seen as the best-performed variable for the case building.

Keywords Building envelope · Environmental variables · Energy modeling · And simulation

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7.1 Introduction

Buildings account for at least 30% of the World's energy consumption and greenhouse gas emissions; thus, their design decisions are significant for reaching sustainability goals and tackling with global climate crisis (Ascione et al. 2021). Excessive building energy consumption and greenhouse gas emissions accelerate global warming and prevent achieving sustainability targets (Giouri et al. 2020). Necessary interventions must be implemented in the buildings. New buildings must be designed energy-efficiently, while existing building stock should be renovated. Because residential buildings are responsible for 75% of energy consumption in the construction sector (Intergovernmental Panel on Climate Change 2015), they convey a high potential for decreasing energy use and its related greenhouse gas emissions (Vishwamitra and Somaroo 2020).

Space heating and cooling, cooking, electrical equipment use, water heating, and lighting contribute to a residential building's energy load (International Energy Agency (IEA) 2013). In the future, there will be greater demand for building energy use. The study of Yang et al. (2021) intended to thoroughly examine the effects of climate change on energy efficiency and thermal comfort in European residential buildings. The findings show that there will be more cooling demand and less heating demand in the future. Building energy performance is affected by many variables.

Environmental and envelope properties are some of the most significant and primarily investigated variables. Environmental variables include the building orientation and surrounding environment, i.e., buildings, ground surfaces, geography, and climate. The building envelope comprises the foundation, walls, windows, roof, and doors. Aydınol (2016) proved that the transmittance of the building envelope significantly influences buildings' energy performance. Different glazing types and transmittance values are applied on different facades of buildings in various climatic zones. It is noted that each façade responds differently to the scenarios. Saeed et al. (2021) proposed that its roof properties and orientation strategies highly influence a residential building's energy consumption in the warm climate of Kirkuk, Iraq. The building envelope components and orientation are directly associated with the building's total heat gain/loss and heat transfer, affecting its energy demand. Nasrollahzadeh (2021) developed an optimization methodology of building envelope components to understand their influence on a residential building's energy, daylight, and thermal performance in Iran's humid subtropical/Mediterranean climate. The variables in the study are wall and roof material and thicknesses, window-to-wall ratio, and glazing and shading device types. The study emphasized the importance of defining proper building components in the design phases of buildings. Studies have shown that environmental variables and building envelope components significantly affect a residential building's energy performance. Although some studies in the literature test these variables' effect on building energy consumption, more detailed analyses must be conducted for each variable that may influence a building's energy demand. Thus, this study aims to evaluate the potential of a residential building in the Mediterranean climate of İzmir, Turkey, whose design process is still ongoing, in terms of decreasing

energy use, and explore the importance of architectural decisions in the design phase of buildings. The study demonstrates the relationships between architectural design decisions and building energy performance. It exemplifies using tools to simulate building performance and incorporate ambiguity and appropriate assessments into building performance evaluation throughout the design stage.

7.2 Material and Methods

7.2.1 Study Design

Firstly, a residential building in the Mediterranean climate in İzmir, Turkey, whose design process is ongoing, is selected for the study. Then, the reference building is modeled, and its energy performance is simulated in the DesignBuilder dynamic simulation software. The study investigates several variables' influence on a residential building's energy performance. The variables' effects are tested individually in eight different scenarios. The variables in the study and respective scenarios are (1) surrounding buildings, (2) building orientation, (3) ground surface materials, (4) building envelope materials' (i.e., wall, roof, and floor) thermal transmittance values, (5) glass, opening frame, door types, (6) shading elements, and (7) natural ventilation. The simulation engine calculated the room's electricity, heating, cooling, and total kWh and kWh/m² energy consumption. The results are compared to the base case results in which no implementations and modifications are applied to the building. Scenario results are calculated by the simulation engine and analyzed in detail. Results are compared and presented both in tables and graphs.

7.2.2 Case Building

A reference building is selected to assess the building's energy performance. The "A House" was designed as a residential building on the Aegean Sea coast in Narlıdere, İzmir, west of Turkey. The elevation from sea level is 2 m. The city has a Mediterranean climate with warm and rainy winters and hot and dry summers due to its proximity to the Aegean Sea (Çetinkaya et al. 2017). The surrounding environment is almost suburban, primarily consisting of 2–4 story residential buildings. The reference building comprises four stories with a total closed area of 373 m². Each floor has an area of 111 m², except the roof floor, with an area of 38 m². The orientation of the building to the North is 342.5 °C. The house has one living room, kitchen, and three bedrooms, and it is occupied by four people, one woman and three men.

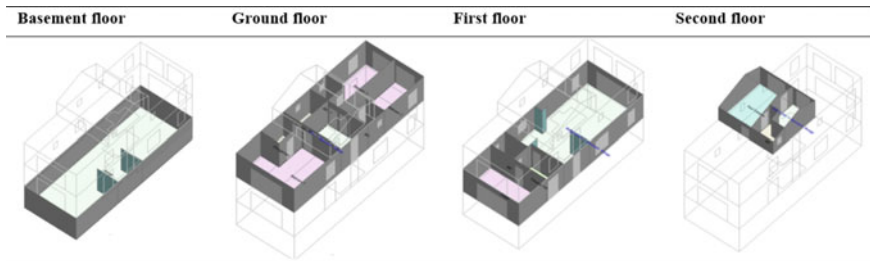


Fig. 7.1 An axonometric view of each story representing thermal zones in DesignBuilder Software

7.2.3 Simulation Models

The simulation model is generated on DesignBuilder v7.0.1.006 energy modeling and simulation software (see Fig. 7.1). DesignBuilder is a dynamic simulation software that uses EnergyPlus as the calculation engine (Download 2021; EnergyPlus 2021). It works with multi-zone approach modeling; each zone corresponds to its schedule and specification (Outgouga and Hicham 2022). An EnergyPlus weather file of İzmir-ADB is selected for climate-based simulations. HVAC systems and construction materials for windows, walls, roof, unoccupied roof, ground floor, and interior floors are assigned. The whole building is heated and cooled throughout the year except for the basement floor. Activity schedules and equipment are also introduced to the software. The base case situation is modeled in the DesignBuilder simulation software. All the inputs for the base case situation are presented to the simulation engine as in Table 7.1. All the rooms have their schedules for occupancy, computer and office equipment use, catering, and miscellaneous tools. Surrounding buildings, streets, and trees are modeled in DesignBuilder. Their materials and schedules are also defined for the sensitivity of the analysis. Energy consumption is calculated for seasonal heating and cooling, annual room electricity, and total energy consumption in kWh and kWh/m². Room electricity is identical for each scenario since no implementation is based on electrical equipment and tools.

7.3 Results and Discussion

7.3.1 Base Case Results

In the base case modeling, surrounding buildings and ground surface materials, e.g., road types and green areas and their annual schedules, are included in the calculations for sensitive and proper analysis. According to the existing design decisions of the building, the total consumption for heating and cooling is calculated as 46,587 kWh, which equals 124.7 kWh/m². The total consumption of natural gas and electricity is

Table 7.1 Data input details and schedules for the energy simulation model

Base program		Building area			
		Living room + kitchen	Bedroom 1	Bedroom 2	Bedroom 3
People	People/area	0.055	0.058	0.05	0.051
	Occupancy	Until: 07:00, 0, Until: 08:00, 1, Until: 09:00, 0.5 Until: 18:00, 0.25 Until: 20:00, 1 Until: 24:00, 0.5	Until: 07:00, 1 Until: 24:00, 0	Until: 07:00, 1 Until: 20:00, 0 Until: 24:00, 1	Until: 07:00, 1 Until: 20:00, 0 Until: 24:00, 1
Electricity equipment	Watts/area	5.54	–	–	–
Miscellaneous	Watts/area	1.66			5.10
Doors	Schedule	Closed	Closed	Closed	Closed
Natural ventilation	Min. indoor temperature (°C)	21	21	21	21
	Max. indoor temperature (°C)	28	28	28	28
HVAC condition	Energy source	Natural gas/ electric	Natural gas/ electric	Natural gas/ electric	Natural gas/ electric
Heating/ cooling setpoint	Degree (°C)	21/19 26/28	21/19 26/28	21/19 26/28	21/19 26/28

50,054 kWh. The results convey that the highest annual energy consumption values share due to space heating and natural gas usage. Base case building's lighting, heating, and cooling energy consumption cover total energy consumption by 6.92%, 84.1%, and 8.98%, respectively.

7.3.2 Scenario 1: Effect of Surrounding Context

In this scenario, the model has no surrounding building, while ground surface materials are kept as default as assigned by the software. The aim is to understand the surrounding context's effect on the building's annual energy consumption. The simulation engine consists of all the schedules, materials, equipment, and systems as in the base case model. Total energy consumption (i.e., heating and cooling load) is calculated as 46,459 kWh, which equals 124.33 kWh/m². The electricity energy

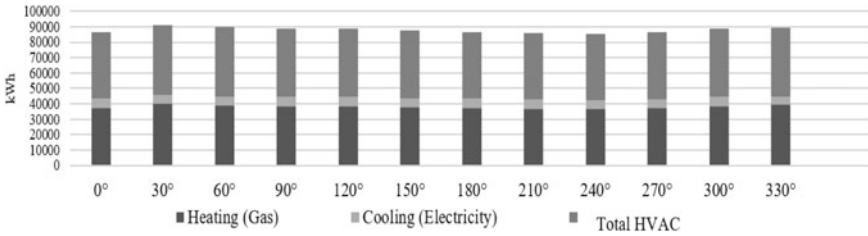


Fig. 7.2 Distribution of energy consumption for heating, cooling, and total HVAC

consumption of the building is estimated as 9521 kWh the consumed gas is calculated as 36,936 kWh. Results show no significant difference in the total heating and cooling energy consumption compared to the base case. It may be due to the building being in a suburban area with low-rise buildings and a low-dense urban fabric. Thus, the effect of the surrounding context is found to be minor for the reference building.

7.3.3 Scenario 2: Effect of the Orientation

In the second scenario, the case building's energy performance with different orientations is individually simulated and compared to determine the best orientation for the first scenario. The building is rotated along with the surroundings. An orientation of 240° is defined as the best to provide the least energy consumption (see Fig. 7.2). Results show that an orientation of 30° has the highest energy consumption and is thus defined as the worst orientation. Total energy consumption is calculated as 122.62 kWh/m² for the best orientation. It is 133.90 kWh/m² for the base case and 130.54 kWh/m² for the worst orientation. The total energy decrease of 9.24% is provided when the first scenario and orientation of 240° are compared.

7.3.4 Scenario 3: Effect of Surrounding Context with Default Materials and Schedules

The difference between this scenario and the base case model is that the software default-defined materials and schedules of the surrounding context, e.g., trees, buildings, roads, etc. The software-defined materials for the surrounding buildings and ground surfaces as plastic. They had a transmittance of 0% and a schedule of 24/7.

Trees had 0% transmittance and 24/7 throughout the year. In this scenario, surrounding building and ground surface materials are defined as plaster, asphalt, pavement, and soil. The schedule of the trees is changed as summer (northern hemisphere), and their transmittance is defined as 50%. The aim is to see the materials and schedules' effect on the building's energy performance. According to the results,

there could achieve no significant difference in the building's energy performance. It may be because the building is located in a suburban area with low-rise buildings, and natural materials are used in the surrounding context.

7.3.5 Scenario 4: Effect of Thermal Resistance on the Components of Building Envelope'

In this scenario, the building envelope components' thermal resistance is changed. These components are walls, floors, and roofs. U-values of walls are decreased to 0.2, external/ground floor to 0.3, and flat/pitched roof to 0.3 W/m² K. All the implementations and previous values can be seen in Table 7.2. The TS825, the national regulation of Turkey, defined existing U-values. According to the results, the total energy consumption from heating and cooling is calculated as 35,383 kWh, equal to 94.7 kWh/m². The total energy consumption from gas and electricity is calculated as 38,850 kWh. Consumption decreased by 24.1 and 22.4% compared to the base case situation. It is noted that building component U-values significantly influence the case building's energy consumption.

7.3.6 Scenario 5: Effect of Glazing, Windows, and Doors

In this scenario, the material properties of glass panes of windows, doors, and framings are changed. U-values of glass panes, window framing, and door framing are decreased to 1.49 W/m² K, 1 W/m² K, and 0.7 W/m² K, respectively, as seen in Table 7.3. This scenario aims to understand the effect of the properties of glass surfaces and their selection criteria on building energy consumption. Windowpane is selected as double glazing filled with argon, while the window frame is defined as plywood. This change shows that total energy consumption from heating and cooling is calculated as 43,689 kWh, which equals 116.92 kWh/m² K. The total consumption of electricity and gas is calculated as 47,156 kWh. Compared to the base case, these decreased by 6.63 and 6.14%.

7.3.7 Scenario 6: Effect of the Shading Element

In this scenario, different shading elements are implemented in the windows of the base case. Two sun-shading elements and one fixed window shading are applied to only south-facing windows. Local shadings are selected as drapes with medium weaves and blinds with medium reflectivity slats. They kept close when solar radiance exceeded 120 W/m². Fixed window shading element is defined as 0.5 m overhangs.

Table 7.2 Proposed building materials for Scenario 4

Component	Material	Specific heat (J/kg-k)	Density (kg/ m ³)	Thickness (m)	U-value (W/ m ² K)	
					New	Old
External wall	Gypsum plasterboard	1000	900	0.01	0.20	0.70
	Cement/plaster	840	1860	0.03		
	EPS expanded polystyrene	1400	10	0.12		
	Concrete block	1000	600	0.20		
	Cement/plaster/ mortar -gypsum	840	1200	0.03		
Below grade walls	Lean concrete	1000	1000	0.02	0.20	0.70
	XPS extruded polystyrene	1400	35	0.07		
	Curtain wall	1000	1400	0.25		
	Board insulation	840	160	0.08		
	Cement/plaster/ mortar	840	1680	0.10		
Basement floor	Clay underfloor	2085	1500	0.25	0.47	0.47
	Brick slips	1000	1700	0.02		
	Curtain wall	1000	2000	0.10		
	EPS expanded polystyrene	1400	15	0.06		
	Flooring screed	1000	1200	0.05		
	Ceramic, glazed	840	2500	0.02		
Flat roof	Ceramic tile	840	2500	0.02	0.30	0.44
	Asphalt	1000	2100	0.19		
	Concrete	1000	300	0.10		
	XPS extruded polystyrene	1400	35	0.04		
Sloped roof	Wooden board	1000	2100	0.02	0.30	0.44
	Air gap 15 mm	0.01				
	Mineral fiber/ wool	1000	99	0.10		
	Roofing felt	834	960	0.01		

The best-performed shading element is defined as blind with high reflectivity slats. In that scenario, the total energy consumption from heating and cooling is calculated as 46,520 kWh, which equals 124.5 kWh/m² K. Table 7.4 shows the distribution of energy for heating and cooling. The gas and electricity consumptions are calculated as 49,987 kWh, as seen in Table 7.5. Results are increased by 0.14 and 0.13% compared

Table 7.3 Proposed glazing, window, and door materials for Scenario 5

Building component		Material	U-value (W/m ² K)
Glass pane	Former	Double glazing clear glass	1.98
	New	Double Low-E glazing filled with Argon	1.49
Glass frame	Former	Painted wooden window frame	3.91
	New	Plywood (lightweight)	1.02
Door	Former	Painted oak	2.99
	New	Opaque door	0.70

Table 7.4 Distribution of energy for heating and cooling results for Scenario 6

Shading type	Room electricity (kWh)	Natural gas heating load (kWh)	Electricity cooling load (kWh)	Total energy consumption (kWh)
Blind with high reflectivity slats	3466.86	42,147.82	4372.73	46,520.55
Drapes open wave dark	3466.86	42,098.72	4492.51	46,591.23
Louvre—0.50 m overhang	3466.86	42,144.02	4492.13	46,636.15

Table 7.5 Fuel total results of Scenario 6

Shading type	Electricity consumption (kWh)	Gas consumption (kWh)	Total energy consumption (kWh)
Blind with high reflectivity slats	7839.59	42,147.82	49,987.40
Drapes open wave dark	7959.37	42,098.72	50,058.09
Louvre—0.50 m overhang	7958.98	42,144.02	50,103

to the base case situation. The effect of the shading element on energy consumption may be minor due to low solar radiation on the window surface.

7.3.8 Scenario 7: Effect of the Natural Ventilation

This scenario aims to test the effect of natural ventilation on building energy consumption. A natural ventilation schedule is applied to the building. All above-ground rooms are ventilated naturally. The prevailing wind directions of İzmir are southeast and west. Thus, natural cross ventilation reduces cooling loads, especially

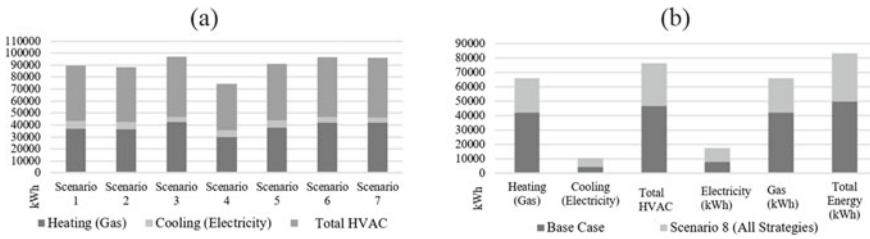


Fig. 7.3 a Comparison of scenarios b Energy consumption for heating, cooling, and electricity for the base case condition and Scenario 8

in the east–west. In the summer period from March 31 to September 30, a natural ventilation schedule was applied from 9 am to 6 pm to reduce indoor air temperatures. The results provided that the total energy consumption from heating and cooling is calculated as 46,297 kWh, corresponding to 123.9 kWh/m² K. The total consumption from gas and electricity is calculated as 49,764 kWh. These are decreased by 0.62 and 0.58% compared with the base case situation. This decrease was observed to be 6.42% in only cooling energy consumption.

7.3.9 Scenario 8: Combining Scenarios 4, 5, 6, and 7

A merged model is created by combining scenarios 4, 5, 6, and 7. These scenarios performed the best in reducing the energy consumed for the building. Thus, they are combined, and a new model is created. In this model, U values of building components, windows, and doors are decreased; shading elements are applied, and natural ventilation is enabled. According to the results, the total consumption from heating and cooling is calculated as 29,751 kWh, equal to 79.6 kWh/m². The total consumption from gas and electricity is calculated as 33,218 kWh. These are decreased by 36.1% and 33.6%, respectively. The implementations significantly affected the building's annual energy consumption (see Fig. 7.3).

7.4 Conclusion

This study displays a comprehensive analysis of the impact of environmental and envelope-related variables on the energy performance of a residential building during the design stage in the Mediterranean climate of İzmir, Turkey. The study aims to understand the effectiveness of the early design decision on the energy performance of residential buildings.

The scenarios are tested using the energy simulation models regarding room electricity, heating, and cooling loads. Among the applied scenarios, building envelope

components' thermal resistance significantly affects the energy saving of heating the case building. A lower U-value provides better insulation, thus, can reduce the heating loads in primarily heated buildings. Thus, in such climates, it may be preferable to use low U-value building components to increase thermal resistance and reduce building heat losses. Regarding the energy-saving of cooling loads, the best results were obtained when natural ventilation was applied on the first floor. Natural ventilation can decrease indoor air temperatures and provide thermal comfort for occupants, especially during summer when the outdoor air temperature reaches extreme heat. Thus, natural ventilation can be a tool for such climate regions to reduce indoor air temperatures and decrease the cooling load of the building. The minor effective variables for this case building were the surrounding context, materials, and heating and cooling energy consumption schedules. It may be because the case building is located in a suburban area where the surrounding buildings are low-rise and constructed with more natural and urban-friendly materials. Thus, their effect may have become neglectable in this sense. It is equally essential to retrofit total energy consumption, especially in Mediterranean climates where heating and cooling energy consumption are similar. When the total annual energy consumption is analyzed and compared, envelope-related variables are performed better than the environment-related variables in terms of the energy saving of the building. In this respect, it was observed that energy-saving improvement with building envelope-related variables is more effective than environmental-based ones for the case building. Comments on the overall research can be gathered to discuss how climate change scenarios and the design process relate to one another, how to use tools for simulating building performance, and how to incorporate ambiguity and proper analyses into building performance evaluation during the design stage.

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