Evaluation of the building envelope to achieve comfort standards in an office building in Izmir

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Abstract. The rapid increase in the world energy use causes the depletion of various resources and has severe environmental impacts such as global warming and climate change. In this context, one of the measures taken throughout Europe is “nearly zero energy building”. The purpose of this study is to examine the effect of a passive design strategy, the design of the building envelope in reaching the comfort standards of an office building in Izmir. The analysis method is to investigate selected variables in a hypothetical office building within the context of reaching a nearly zero energy building via building energy simulation. Four scenarios were modeled included changing the wall-window ratios of façades, changing the window glass type, adding insulation material to opaque building components, and adding shading elements to the facades respectively. Finally, the scenarios are discussed through yearly analyses of heating and cooling loads. The results show that the passive strategies that aim to decrease the cooling loads cause higher reductions in the energy demand of the building in Izmir. Consequently reaching a nearly zero energy office building is not feasible with the evaluated passive design strategies; however they can play a significant role in decreasing the total energy consumption of the building.

1 Introduction

The rapid increase in world energy use leads to the depletion of energy resources and has caused severe environmental impacts such as global warming, ozone depletion and climate change. While buildings account for about 70% of sulfur oxides and 50% of carbon dioxide (CO_2) emissions, they consume about 40% of the world's energy consumption, 16% of the world's fresh water and 25% of the forest timber [1]. Energy use in the built environment is estimated to increase by 34% over the next 20 years. Also in 2030, the consumption attributed to houses and non-domestic sectors is expected to increase to 67% and 33%, respectively [2].

The concept of zero energy building (ZEB) is now perceived as a realistic solution to reduce CO_2 emissions and / or energy use in the construction sector, and not as a distant future concept. An increasing number of ZEB projects and research in this area highlight the increasing international interest in ZEBs. The objectives for the implementation of ZEBs are discussed European level within the recast of the Directive on Energy Performance of Buildings (EPBD) adopted in May 2010 [3]. As of 2018, the EPBD has set out to be a "nearly zero energy building" as a building target for all public buildings or public administration buildings of the public authorities and for all new buildings after 2020. In the studies carried out to date, the concept of ZEB has been defined with a wide variety of expressions, and different approaches to ZEB definitions can be distinguished. The lack of a generally accepted definition of ZEB is currently debated at international level [4].

The facade affects the building's energy budget and comfort more than other systems in most buildings. In the design process of high-performance building facades, directives specific to climate principles must be taken into account. The basic methods for designing high-performance building facades are: Arranging building orientation according to the position of the sun; Using natural ventilation to improve air quality and reduce cooling loads; Minimizing the energy use of mechanical heating / cooling by optimizing the opaque components of the building shell with insulated material; Increasing the use of daylight to minimize the use of artificial lighting and mechanical heating/cooling use by optimizing transparent components of the building variables such as window / wall ratio (WWR), visible light transmission of glazing (VLT), U-value and solar heat gain coefficient (SHGC); Shading to control cooling loads and increase thermal comfort [5].

There are many studies on the optimization of building energy consumption through simulation programs in the literature. Boyanoa A, Hernandez P and Wolf O [6] investigated the effect of different improvement scenarios on the energy consumption and economic performance of the building. Two scenarios with different lighting control systems, two scenarios for the improvement of glass and wall insulations, and two different building orientation variables were calculated for three places representing three climatic regions of Europe. Yıldız et al. [7], investigated the effect of window-wall area ratio on the building energy performance of an educational building in Izmir. Accordingly, they calculated that the eastern and western facades are the most effective and the northern facade has the least effect in terms of total energy consumption. When using low-e coated glass instead of double glazing (base case), they found that the same effects is obtained according to directions. Altan et al. [8], presented thermal balance and daylight level analysis of residential areas. In this context, four different hypothetical spaces with different windows has been modelled. The thickness of the extruded polystyrene (XPS) as the thermal insulation layer of the outer wall and the double glazed and triple glazed features of the windows are the parameters for evaluation. The simulation outputs provided information about optimal facade design for energy efficiency and favorable daylight in buildings with temperate climates.

The use of Building Performance Simulation (BPS) tools at the beginning of the design process is indispensable for assessing the challenges of energy efficient building design. Decisions taken at the early design stage affect 80% of all design decisions [9]. Although there are similar scenarios in the literature, there is a lack of studies which use simulation programs as a decision support tool and aim to optimize environmental comfort, in terms of office buildings in the Mediterranean climate regions. Therefore, the aim of this study is to evaluate the effect of building envelope in an office building to reach the comfort standards in the city of Izmir, Turkey. In this context, the basic methods for designing high performance building facades, which are mentioned above will be examined comparatively.

2 Methodology

The methodology of the investigation is modelling a hypothetical nearly zero energy office building, to calculate the heating and cooling designs of the selected variables and the base case, and to compare the total energy loads calculated by building energy simulation.

Selected simulation engine for this study is EnergyPlus, a 3rd generation dynamic building energy simulation engine developed by the US Department of Energy to model building, heating, cooling, lighting, ventilation and other energy flows. DesignBuilder 5.0.3.007 [10], which is a graphical interface of EnergyPlus simulation engine, is used in this study.

2.1 Building Description and Building System

The hypothetical office building examined is supposed to be completed in 2019. The location of the building is 38°27'3.93" North; 27°10'52.42" East with 2m altitude. The building will comprise of 8-stories and each floor will have the same open-plan office.

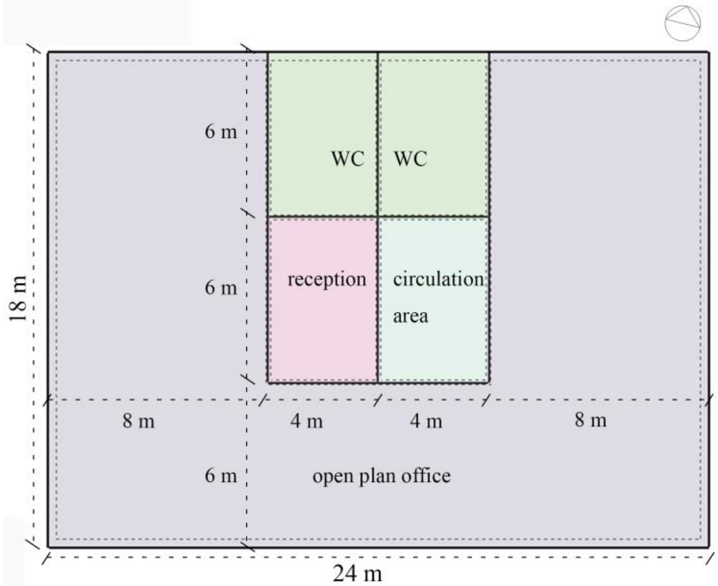

Fig. 1. Floor plan of the building.

The floor plan of the building is a rectangle with a north-south façade of 24 m and an east-west facade of 18 m (Figure 1). Its floor height is 3.5 m. It has a 30° gable roof with 50 cm eaves. The plan is divided into 7 thermal zones: the reception, the core, two WCs and an open-office space oriented towards three different directions, with no separators in between. Table 1 summarizes the general characteristics of the building.

Table 1. General characteristics of the building.

Location of the building	38°27'3,93" North; 27°10'52,42" East
Altitude	2 m
Year of construction	2019
Orientation	North-South
Number of floors	8
Floor height	3.5 m
Floor area	432 m² (18x24 m)
Building total area of use	3456 m² (18x24x8 m)
Building total volume	96768 m³ (3456x8x3.5)
Heating system	Fan coil (natural gas)
Cooling system	Split airconditioner

The opaque parts of the building envelope consists of layers defined as in Table 2 and their thermal conductivity values are also given there. In addition the recommended U-values (thermal conductivity) in the thermal insulation standards for buildings in Turkey TS825 are indicated [11].

The properties of the transparent envelope elements of the building include both the geometric data (the window wall ratio) as well as the thermophysical properties of the windows. In this context, the window-wall ratio of the north, south, east and west facades of the building is 20%, 30%, 40%, 40% respectively. The thermophysical properties of the windows are given in Table 3. The parapet wall of the window is 80 cm and height of the windows are 150 cm.

The office is used between 07.00-19.00 hours except weekend and holidays. HVAC elements do not work except for working hours. Table 4 summarizes the HVAC data that determine the energy loads of the building. The target illumination for the office area, corridors and auxiliary spaces of the building is 500 lux. This value is the minimum value for the office areas specified in EN 12464-1.2009 [12]. The heating / cooling energy of the building is met by a natural gas-powered 4-pipe Fan Coil Unit with an air-cooled chiller. The heating performance coefficient (COP value) of the air conditioning system is 0.85 and the cooling performance coefficient is 1.8. The climate data of the city of Izmir, which has a Mediterranean climate, is taken from the database of US Department of Energy generated for use in EnergyPlus.

Table 2. Parameters of the opaque envelope elements.

Building Envelope Component	Layers	Thickness (m)	Thermal conductivity (W/m²K)	U-value (W/m²K)	U-value recommended in TS825 (W/m²K)
Roof	Tile roofing Air space Waterproofing Screed R.Concrete slab Ceiling plaster	0.015 0.05 0.006 0.04 0.12 0.02	1 - 0.25 0.88 2.5 0.4	1.878	0.45
Wall	Exterior plaster Hollow brick Interior plaster	0.03 0.19 0.02	0.42 0.72 0.4	1.801	0.7
Floor	Laminate flooring Particleboard Mounting Elements Correction screed R.concrete foundation Waterproofing Lean concretev	0.01 0.05 0.04 0.4 0.006 0.15	0.14 0.15 0.41 0.16 0.25 1.13	0.297	0.7

Table 3. Parameters of transparent building components in base case and in Scenario 2.

Glass Type	U-value (W/m²K)	Visible light transmission (VLT)	Solar heat gain coefficient (SHGC)	Thickness (mm)	Joinery type
Double glass (base case)	2.725	0.801	0.742	4mm clear glass + 12 mm air + 4mm clear glass	Aluminium joinery with thermal break
Low-e coated double glass	1.931	0.721	0.634	4mm Low-e glass + 12 mm air + 6mm Low-e glass	Aluminium joinery with thermal break

Table 4. Building's main operating conditions.

Occupancy hours	7-19 h	Hours Monday to Friday
Density of occupation	0.11	person/m²
Metabolic rate	120	W/person
Set point cooling	24	°C
Set point heating	22	°C
Hot water	0.2	l/m² day
Ventilation	10	l/person second
Equipment	12	W/m²
Target iluminance	500	lux

3 Optimisation of building energy consumption

The possible contribution of 4 different scenarios in reducing building energy consumption was evaluated. In order to compare the measures taken, each scenario will be implemented individually. The scenarios and changing parameters are as follows:

Scenario 1: Changing facade transparency ratios; The WWR of southern facade was increased to 40%, the eastern and western facades were reduced to 30% and the northern facade was left as 20%.

Scenario 2: Improving the parameters of transparent building components by changing the glass type to low-e coated double glass (Table 3).

Scenario 3: Adding 5cm XPS extruded polystryne to opaque building components; The U-values of the roof, wall and floor became 0.499, 0.494, 0.207 W / m²K respectively, with the addition of a material with of 0.034 W / m²K U-value.

Scenario 4: Adding shading elements to facades; 50 cm aluminum overhangs on south side and 50 cm aluminum vertical sidefins on east and west facades.

4 Results and conclusion

In this study, it is aimed to compare the heating and cooling loads of the building in different scenarios through a hypothetical office building. Four different improvement scenarios and base case were modelled in DesignBuilder. These scenarios are changing the window-wall ratios, changing the parameters of the transparent building components by changing the glass type, adding 5cm extruded polystyrene to opaque building components and using overhangs to the south and sidefins to the west and the east facade.

Heating and cooling loads of five scenarios, including the original version of the building, is calculated. In this section, firstly the results of heating design and cooling design, then yearly analyses will be evaluated.

The heating design of the building, which is calculated according to the winter design day, is based on the steady-state method [13]. Figure 2 shows the steady-state heat losses in each scenario. The heating boiler of the building is selected by this value obtained by multiplying a design margin (taken as 1.25 in this study). According to the graph, the maximum heat loss is experienced in scenario 1 where the WWR of the southern front was increased and the eastern and western facades were reduced. This is followed by scenario 4 in which the outer shading devices are added, base case and scenario 2 where the glass type is changed respectively. However, there are no significant differences between these 4 scenarios with average 6kW. In scenario 3, where insulation is added to the opaque building components, has minimal heat loss and has 43 kW less heat loss from scenario 2 and 58 kW less from scenario 1. The result is that the most important effect on the heating design is obtained by adding insulation to the opaque building components. Increasing the transparency in the south facade increases the solar heat gain although the heat loss from inside to outside is more. Due to the fact that the shading elements are constant, the heating design has a negative impact on the winter days when solar heat is needed.

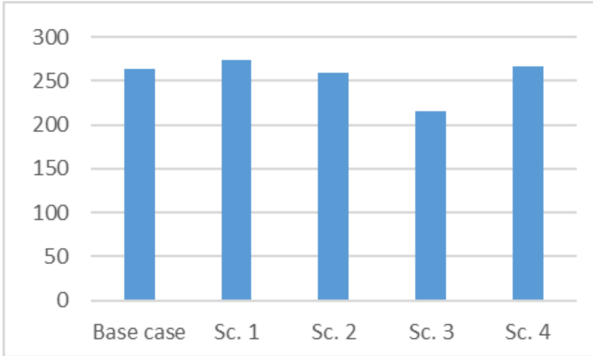

Fig. 2. Comparison of steady state heat loss values [kW].

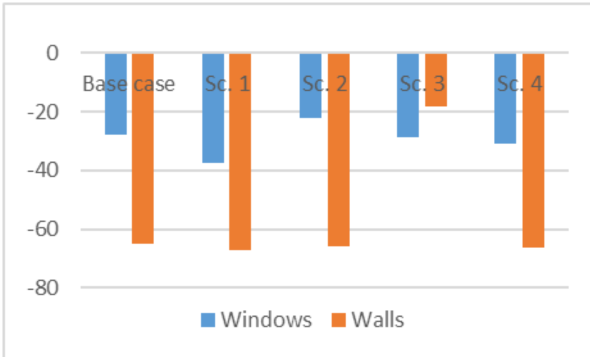

Fig. 3. Comparison of heat loss values of windows and walls [kW].

Heat losses from windows and walls are compared in Figure 3. As can be seen from the chart, the losses in the walls in scenario 3 are critically reduced. The losses in other scenarios are very close. The losses in the windows are the lowest in scenario 2 where low-e coated glass is used. These are followed by base case and scenarios 3, 4 and 1. As a result, the scenario in which the losses are the highest is the situation in which the window / wall ratio in the south direction is increased and those in the east and west direction are reduced.

The cooling design of the building is done according to the characteristics of the summer design day of July 15 with dynamic design [13]. Total cooling loads are given in Figure 4. Accordingly, the lowest cooling load is in scenario 3 where insulation is added to opaque building components. This is followed by scenario 2 with low-e coated glass. There is almost no difference between the scenario of the shading element and the base case. The scenario with the highest cooling load is scenario 1, in which the WWR changed. It is interesting that improving the opaque building components results better than improving the transparent building components. The addition of a shading element is found to be negligible, while it is thought to reduce the cooling load. It is an expected result that increasing the transparency in the south will increase the cooling load due to the increase of solar heat in Izmir climate conditions.

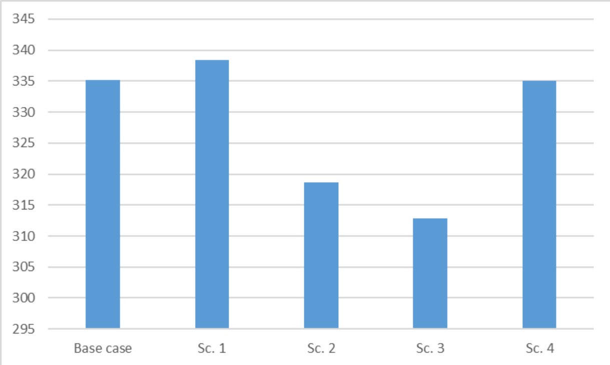

Fig. 4. Comparison of cooling load values at summer design day [kW].

Heating and cooling desig has been carried out to determine the capacity of the heating and cooling system, which needs the coldest and hottest weather conditions of the building. As for the capacity of the heating and cooling system requirements will vary according to the passive climatization measures, the heating and cooling design data are compared above. However, in order to obtain more meaningful data about energy efficiency, the annual total heating - cooling - lighting loads of the building must be compared as shown in Table 9. The heating data for the scenarios in the table are compared in Figure 5, while the cooling data are compared in Figure 6 and the lighting data in Figure 7.

As a result of comparing the annual total heating loads in Figure 5, it is seen that the addition of insulation to the opaque building components in scenario 3 has the greatest positive effect. While the use of low-e coated glass is more positive than base case, adding shading devices in scenario 4 and changing WWR in scenario 1 has resulted with more heating energy consumption than the base case. However, since the heating energy requirement is very low compared to the cooling and illumination, the changes in heating energy did not show much effect on the total energy loads.

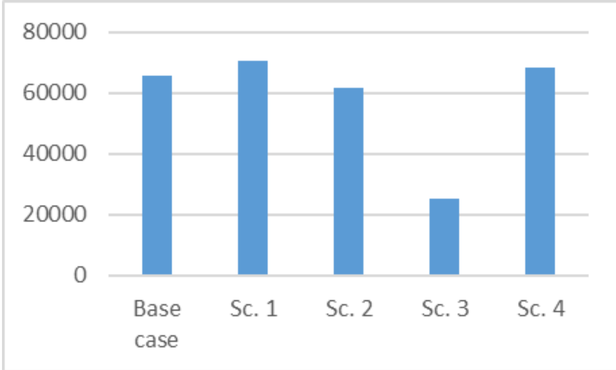

Fig. 5. Comparison of annual total heating loads [kWh] for all scenarios.

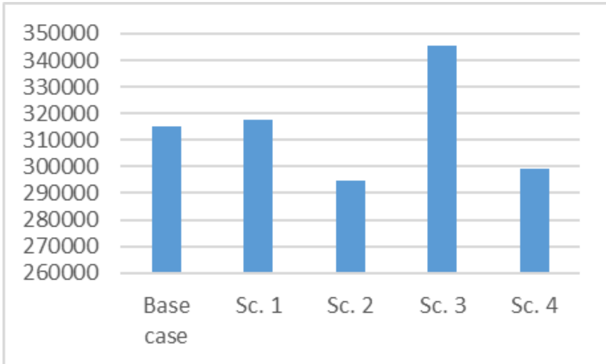

Fig. 6. Comparison of annual total cooling loads [kWh] for all scenarios.

As a result of the comparison of the annual total cooling loads in Figure 6, the use of Low-e coated glass in scenario 2 has the greatest positive effect. Adding external shading devices (scenario 4) has a higher energy load scenario 2 with little difference. Changing WWR in Scenario 1 is closer to the base case and requires more cooling energy than the base case. Addition of insulation to opaque building components has significantly increased cooling loads. The largest energy load is due to the need for cooling energy in general situation.

Annual total indoor lighting loads are compared in Figure 7. Accordingly, the addition of insulation to opaque building components made the most positive effect. Adding exterior shading devices and changing the WWR of the facades are similar. Besides, there is no significant difference between the electricity consumption of the scenarios.

Table 9. Annual total heating-cooling-interior lighting loads [kWh].

	Base case	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Heating	65944.65	70842.49	61635.67	25097.07	68536.81
Cooling	315313.01	317623.76	294671.93	345232.87	299409.23
Interior Lighting	150877.09	149628.14	150877.09	149351.15	149628.14
Total	532134.75	538094.39	507184.69	519618.09	517574.18

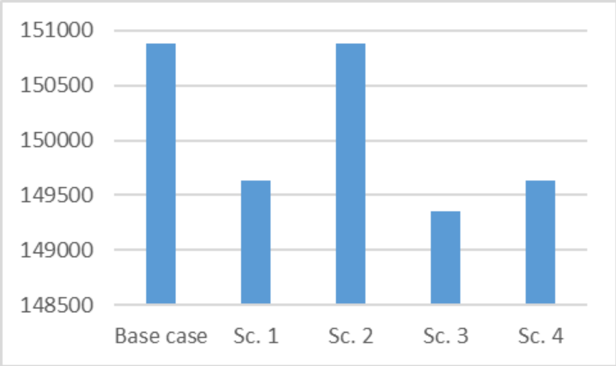

Fig. 7. Comparison of annual total interior lighting loads [kWh] for all scenarios.

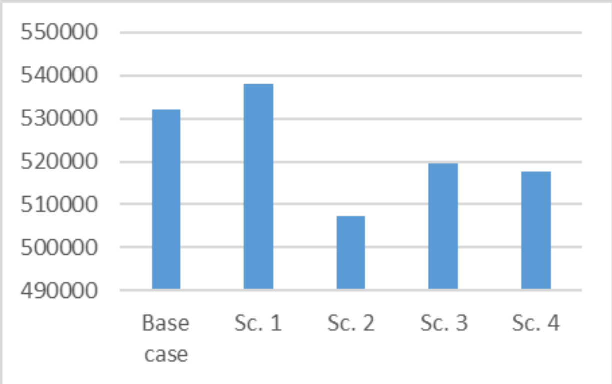

Fig. 8. Comparison of annual total energy loads [kWh] for all scenarios.

Finally, Figure 8 compares the total energy load of all scenarios. According to the chart, the most positive result was obtained by using Low-e coated glass. Adding insulation material to the opaque building components and inserting the exterior shading devices has very close values and is the scenarios that require the least energy use after the use of Low-e coated glass. It was comprehended that the increase in the transparency in the southern front and the reduction of the eastern and western facades caused more energy needs than the base case. In general terms, it is seen that strategies intended to reduce cooling loads have more positive results for decreasing the energy needs of the building in İzmir city.

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