The impacts of window to wall ratio and window orientation on building energy consumption and CO_2 emissions under climate change

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Abstract: Decisions about the openings of the buildings play crucial role for improvements in recent and future energy and environmental performance characteristics. Therefore, the effects of window to wall ratio and window orientation on building annual heating, cooling energy consumptions and operational CO_2 emissions are investigated regarding recent (2018) and future weather conditions (2050s and 2080s) of İzmir. The simulation model of a typical office building is created, and several scenarios are generated, including four facade orientations and different window to wall ratios, simultaneously. Then, the impacts of retrofits in window characteristics on building performance under climate change are examined for İzmir and Ankara. Finally, the results are evaluated in terms of different weather conditions to reach the most efficient opening design alternative. Considering the average life time of buildings, the outcomes of this study can be used as additional data for understanding the relation between transparent surface design and energy, environmental performance of buildings.

Keywords: climate change; global warming; office buildings; window to wall ratio; window orientation; building energy consumption.

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1 Introduction

Nowadays, the rate of energy consumption is increasing day by day, and countries devote majority of their economy to energy production. In addition, CO_2 emissions are increasing due to energy production, which leads to climate change and the effects of global warming become more apparent. In fact, total CO_2 equivalent greenhouse gas (GHG) emissions of Turkey have increased by 122% from 1990 to 2015 (TSI, 2017). For these reasons, the number of studies in terms of reducing energy costs and CO_2 emissions are increasing. Besides, issues such as decreasing energy consumption, investigations of alternative energy production methods and the search for sustainable and ecological friendly resources have recently taken an important place in energy-related researches. The decrease in energy consumption is one step ahead of others as it reduces both energy dependency and carbon emission.

Recently, building energy performance has also been a significant issue since buildings account for large percentage of total energy consumption worldwide. For instance, the report, published by The Turkish Ministry of Energy and Natural Resources (MENR, 2014) indicates that residential and commercial buildings constitute the largest energy consuming group in Turkey with 33% of total amount. In Europe, buildings account for 40% of overall energy consumption and 30% of CO_2 emissions (Maccari and Zinzi, 2001). Accordingly, buildings are one of the most effective factors for reducing energy consumption. The number of studies examining the impacts of climate change on building energy consumption and building design has increased rapidly. The overall aim of these studies is to increase energy efficiency by reducing buildings' energy consumption and CO_2 emissions.

The energy consumption and operational CO_2 emissions in buildings depend mainly on several physical and structural parameters. Constitutively, these are climate, site, wind, topography, material selection and building form and, they can make actual differences in the energy consumption of buildings. One of the initial decisions in design is the location, and site characteristics of buildings. For instance, existence of higher terrains around, such as mountains, has effects on the macroclimate. Therefore, even the smallest differences in site can create significant modifications in the microclimate (Olgyay, 2015). For this reason, it would be necessary to focus on the data about surrounding and environment of the building site during design process.

The area of building is a formation that takes many components into it. The most important of these environmental components are sun, wind and climate (Krautheim et al., 2014). These features are customised and variable according to the type of building. In office type buildings, parameters such as building form, window systems, building envelope, orientation, operation hours and age of building have influences on the energy consumption characteristics (AlAnzi et al., 2009; Tsikaloudaki et al., 2012; Raji et al., 2017; Košir et al., 2018). The building envelope is one of the most crucial of these parameters which has direct effects on the amounts of energy consumed in buildings.

Only by improving the building envelope, energy savings can be achieved up to 41% (Lin et al., 2016). Basically, openings are the most important aspects affecting directly the heating and cooling characteristics of the buildings, since the energy in buildings up to 40% is dissipated by windows (Bülow-Hübe, 2001). For this reason, the selection of window system is an important issue, especially for buildings with wider transparent surfaces, such as office buildings.

There are many features to be considered during window selection. Sunlight and daylight penetration, thermal insulation, window size, glass type, window frame, sound insulation, cost and sustainability are some of the important variables (Duer et al., 2002; Urbikain and Sala, 2009; Jelle, 2013). In addition, providing the balance between opaque and transparent surfaces in buildings is also another parameter affecting the energy performance of buildings. The factors such as window to wall ratio (WWR), window orientation and heat transfer coefficient are significant in window system selection, as well (Lee et al., 2013; Ghosh and Neogi, 2018). Additionally, WWR and window orientation have significant impacts on the CO_2 emissions released from buildings (Komerska et al., 2015). In fact, these two factors increase the annual energy load between 6% and 181% (Alghoul et al., 2017). When WWR factor alone was examined, it was observed that it has a minimum 5% to 25% effect on the total energy load in European climates (Goia, 2016). Besides, the effects of WWR on indoor air quality show changes according to climate type. It is recommended that this rate cannot be greater than 20% in moderate climates and cannot be greater than 10% in hot and dry climates (Alwetaishi, 2017). In severe cold climates, the best heating results were achieved with WWR between 33% and %60 (Liu et al., 2018). In Turkey, only by changing the transparency of the building envelope up to 14%, considerable changes in the energy consumption can be observed (Bostancioglu and Telatar, 2013).

In addition, there will be changes in the energy consumption of buildings in accordance with global warming. It is predicted that the heating loads will decrease, and the cooling loads will increase with warming of the air (Radhi, 2009; Chow and Levermore, 2010; Kolokotroni et al., 2012). Because of global warming in the mild temperate zone, it is predicted that the cooling loads will be more important than heating loads in the future (Karimpour et al., 2015). If no measures are taken for energy consumption in office buildings in Europe, increases in consumption of at least 50% will appear in 2090s climate data (Cellura et al., 2018).

The number of studies about the impact of buildings' openings on energy efficiency has increased significantly over the last 10 years. However, when these studies are examined, it is seen that there are few studies considering the relation between building openings and climate change. In addition, in terms of Turkey, even though many researches about the energy and environmental performances of office buildings have been conducted recently, only few studies have focused on the impacts of climate change on building energy use. In countries with a combination of different climatic conditions such as Turkey, the increase of these studies is of great importance.

Consequently, this study aims to find the impacts of transparent surfaces on building energy consumption and operational CO_2 emissions under climate change. Besides, evaluation of WWR and building orientation are the main design parameters considered for the study, and the impacts of thermal characteristics of windows as well as different climatic conditions are investigated to find better performing solutions for WWR, building orientation and window types for office buildings. Initially, a typical rectangular, five story office building model located in İzmir is used for performance analyses. The base model's WWR is determined as 0.35. Other values of WWR, used for the following simulations, are 20%, 40%, 60% and 80%. For the analyses, recent (2018), 2050s and 2080s weather data were used as climatic parameters. OpenStudio plugin for SketchUp software is used to simulate office building model and calculate annual heating, cooling consumptions as well as operational CO_2 emissions.

In the second phase of the calculations, analyses for the same office building model are carried out with another type of window having a lower heat transfer coefficient to improve the first analysis results due to the modifications in thermal characteristics of selected window type.

Finally, for the third phase of the calculations, analyses were performed by using the same design and window thermal parameters of second phase, however with a different location which is Ankara as a representation of cold-dry climate conditions, in contrast to hot-humid climate of İzmir. The purpose of this further analysis is to observe the behaviour of building performance in two locations with different climate and temperature data for present and future climatic conditions.

2 Methodology

The study mainly aims to estimate the impacts of transparent surfaces on building energy and environmental characteristics with regard to recent, 2050s and 2080s weather conditions for different climate zones. Accordingly, this section defines the methodology used in this study to analyse window systems for reducing building energy loads. As the input data, variations are chosen based on several parameters, namely WWR, orientation, thermal properties of windows, and climate conditions. Besides, several impact categories are identified as the output data. These impact categories include annual heating and cooling loads as energy performance. Besides, this methodology considers global warming potential in assessing the environmental impacts, and the metric selected for this purpose is carbon dioxide equivalents (CO_2e), which measures the total amount of operational CO_2 emissions of the building, considering operational sources.

The analysis process consists of following research framework:

- investigating the effects of WWR and building orientation on a reference office building regarding climate change
- collecting and observing the generated data with respect to energy and environmental performance of the building
- enhancing window performance characteristics under different climate zones (İzmir and Ankara)
- evaluating the simulation results of different window characteristics, different climate conditions and different locations regarding the comparisons between energy and environmental performance variations.

2.1 The weather conditions

Climatic conditions are one of the significant factors to calculate building energy consumption characteristics. Turkey is characterised by different climatic conditions. In recent years, construction of buildings in İzmir, third largest city of Turkey, has increased dramatically. The office buildings are also among the biggest reasons for this growth. Therefore, these buildings have begun to receive more share of the generated energy. Accordingly, as indicated in Figure 1, one of the selected areas for this study is İzmir and located in the west part of Turkey near Aegean Sea, which has hot and humid climate. It is indicated in the Köppen climate classification as a representation of Mediterranean climate, labelled with Csa (Cs – for dry summer, a – for hot summer). The site selected to perform the simulations has climate conditions which is representative of this system. Therefore, it allows a reliable evaluation of the effect of the weather variability on the energy efficiency of the building envelope.

Figure 1 The location of İzmir (1) and Ankara (2) in Turkey (see online version for colours)

Source: Map of Turkey (2015)

Figure 1 also shows the location of Ankara, which is the second largest city of Turkey and placed on a high plateau located between mountains and the grasslands. Therefore, it selected as the other location for current study. The climate of Ankara is very cold with less precipitation in winter, and hot in summer with no rainfall. Under the Köppen climate classification, these types of 'dry-summer subtropical' climates are often referred as 'Mediterranean'. Summers tend to be dry with less than one-third of the wettest winter month, and with less than 30 mm of precipitation in a summer month. Many of the regions with Mediterranean climates have relatively cold winters and very warm summers. The Köppen Climate Classification subtype for this climate is 'Csb'.

Weather information used in simulations for both cities is based on International Weather Files for Energy Calculations (IWEC). Besides, future climate data are employed from HadCM3 climate model in this study to evaluate the impacts of climate change on building energy consumption (Johns et al., 2004). The significant parameters in HadCM3 for creating future weather data contain various parameters such as; relative humidity, wind speed, dry bulb temperature, horizontal solar radiation, total sky cover and total precipitation rate. The emission scenarios used in HadCM3 are Special Report on Emissions Scenario (SRES) A1, A2, B1, and B2 scenarios. The SRES A2 scenario follows a storyline that describes less trade and more self-reliance, slow technological change and consolidated economic regions (Nakicenovic et al., 2000). CCWorldWeatherGen (http://www.energy.soton.ac.uk/ccworldweathergen/), developed by University of Southampton is used as future weather data generation tool. Future weather files are produced for 2050s and 2080s from HadCM3 A2 scenario.

2.2 Building energy simulation data

A reference office building model has been chosen to investigate the impacts of window size, window orientation and thermal properties on energy use and thermal environment. SketchUp is used for drawing and creating the model geometry, while OpenStudio is selected to modify model properties: construction, materials, occupancy, internal loads and schedules. The total building area is 1,428 m^2. The shape of the office building is rectangle and the dimensions of floors are (17.0 × 21.0 × 4.0 m, length × width × height) as shown in Figure 2. The typical floor contains a central core including toilets, elevators and stairs, as well as border spaces indicated as offices. There are four stories and four different thermal zones (offices, hall, stairs and toilets) in the medium-sized office reference model. The WWR of the base case is specified as 35% for all four orientations.

In this study, internal gains are estimated in terms of the general schedule pattern generated for an office building within the program. Natural gas for heating and electricity for cooling is selected to provide the conditioned environment for each floor in order to study the energy performance of the building. Burner efficiency for the heating system and the coefficient of performance (COP) for the cooling system are defined as 0.8 and 3 respectively. The HVAC system operation is set to work between 6:00 to 21:00 during weekdays. The mechanical equipment properties are kept the same for future climate runs. The heating set-point temperature is 22°C and cooling set-point temperature is 26°C. Cooling sensible heat ratio is set around 0.8. The occupancy schedule is set as 0.95 between 8:30 to 12:30 and 13:30 to 17:00, as well as 0.5 between 12:30 to 13:30. Besides, office building equipment and lighting schedule is arranged depending on the occupancy schedule, as well.

The construction of the building is designed based on the schematic and specifications shown in Table 1. Concrete framework structure as well as brickwork fillings for walls are selected for envelope of the building. A concrete flat roof and double clear glazed, air filled windows are chosen for transparent surfaces of the case building. Overall heat transfer coefficients of the windows and the exterior walls are 1.6 W/m^2K, and 0.61 W/m^2K. Detailed attributes of the construction components are also shown in Table 1. Thermophysical properties of the building components are defined in consistence with Thermal Insulation Regulations in Buildings (TS 825).

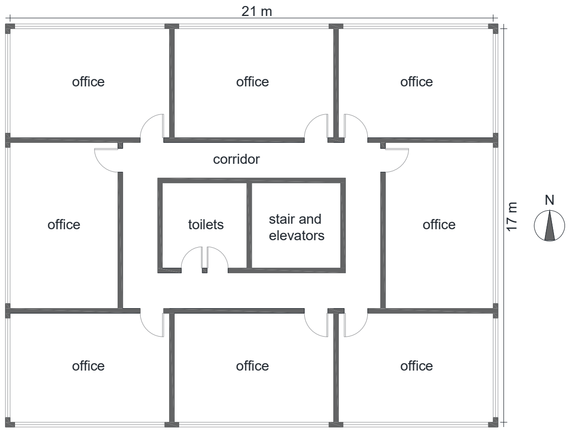
The office spaces are designed symmetrically in opposite directions for more appropriate comparison conditions during energy simulations. Offices located at the corners have two windows placed on external walls while others have only one window.

EnergyPlus 8.1 simulation engine with SketchUp 2017 and OpenStudio 2.3 software were used to calculate required cooling and heating capacity and energy consumption for the office building described above. EnergyPlus is an extensively used and validated simulation tool for assessing the thermal performance of buildings based on the heat balance model, while considering weather data of the building site (OpenStudio, 2018). These programs are also used to perform annual energy simulations based on current and future climatic conditions. Besides, annual operational CO_2 emission properties of the building are calculated based on the annual heating and cooling consumption values. For this calculation, total annual energy consumption values are multiplied by CO_2 emission factors specified in Turkish regulations; as 0.234 kg/kWh for natural gas and 0.819 kg/kWh for electricity (Gazette, 2008). The calculation formula can be seen in equation (1).

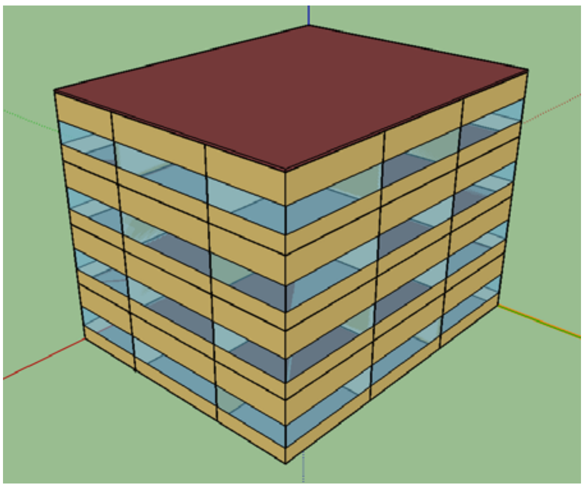
$$OC:(EC_H \times 0.234)+(EC_C \times 0.819) \quad (1)$$

where *OC* means total operational CO_2 emission value ($kgCO_2e/m^2$), EC_H indicates the annual heating consumption value (kWh/m^2), and EC_C indicates the annual heating consumption value (kWh/m^2). Finally, obtained results are evaluated for assessing the most efficient opening design alternatives for an office building located in İzmir.

Figure 2 (a) Plan view of the typical floor (b) 3D model of the building (see online version for colours)



(a)



(b)

Table 1 Components of construction and specifications

BUILDING ENVELOPE COMPONENTS	*POSITION*	*LAYER NAME*	*THICKNESS (m)*	*U VALUES (W/m^2K)*
EXTERIOR WALL	OUTSIDE	Artificial stone tile	0.02	0.61
		EPS expanded polystyrene	0.03	
		Brickwork	0.195	
		Plaster (coarse)	0.02	
	INSIDE	Gypsum plaster	0.01	
FLAT ROOF	OUTSIDE	Ceramic tile	0.03	0.461
		Cast concrete	0.04	
		XPS expanded polystyrene	0.04	
		Bituminous membrane sheet	0.006	
		Cement screed	0.04	
		Cast concrete	0.04	
		Hollow clay tile	0.35	
		Plaster (coarse)	0.01	
	INSIDE	Gypsum plaster	0.01	
INTERIOR WALL	OUTSIDE	Gypsum plaster	0.01	0.985
		Plaster (coarse)	0.02	
		Brickwork	0.195	
		Plaster (coarse)	0.02	
	INSIDE	Gypsum plaster	0.01	
FLOOR	OUTSIDE	Gypsum plaster	0.01	1.005
		Plaster (coarse)	0.01	
		Hollow clay tile	0.32	
		Cement screed	0.05	
		Capron	0.005	
	INSIDE	Flooring blocks	0.012	
EXTERIOR GLAZING	OUTSIDE	Low-e glass	0.004	1.6
		Air gap	0.012	
	INSIDE	Low-e glass	0.004	
GROUND FLOOR	OUTSIDE	Blockage	0.15	0.61
		Sand	0.035	
		Ground concrete	0.1	
		Vapour barrier	0.003	
		Thermal insulation	0.05	
	INSIDE	Cement screed	0.06	
		Ceramic tile	0.03	

2.3 Building design simulation models

After building simulation model generation process, different configurations are created by focusing on design, thermal and climate parameters. All configurations are generated by modifying the base case, which has WWR value of 35% on all four facades of the building. Design parameters included WWR and building orientation. Besides, variations of thermal characteristics of windows are assigned for evaluating the performance of glazing systems in the office building. Furthermore, climatic conditions of İzmir and Ankara as representations of hot-humid and cold-dry weathers are used as climate parameters. Three different groups of scenarios are combined in order to observe the impacts of these parameters on energy and environmental performance characteristics of the office building with respect to recent and future periods.

- *WWR value variations:* initially, the main configurations are generated by making changes in design scenarios. Therefore, the glazing area is varied for each facade separately by using WWR values corresponding to 20%, 40%, 60% and 80% of the wall area, while WWR values of the remaining three facades are arranged as %35. Besides, building energy use is affected by orientation changes, as window systems may be mounted in different faces of buildings. Accordingly, four cardinal orientations including south, east, north, and west are considered for generating WWR variations on each facade. Then, sixteen different configurations are established by combinations of WWR and window orientations, simultaneously. Additionally, the climate data of İzmir is selected for simulations, in terms of observing the correlation between these design scenarios and hot-humid climate conditions. Furthermore, all these configurations are considered for simulations under recent and future climate conditions separately.
- *Window thermal performance improvements:* secondly, the previous simulation characteristics including the variations in design parameters and climate data of İzmir are kept constant. As distinct from the former case, enhancements in window thermal performance characteristics are taken into consideration, since the transparent surfaces are one of the main factors playing crucial role in building energy performance. Therefore, there have been modifications in the rate of heat transfer (U value) of windows. Previous U value of windows were determined as 1.6 W/m^2K (as a representation of classical double glass windows), which is the most common application model in Turkey, whereas the windows are replaced with triple windows with 0.9 W/m^2K U values for generating second simulation group. The purpose is the intent to investigate the amount of changes in annual heating and cooling consumption as well as operational CO_2 emissions of the building with respect to the variations in thermal characteristics of windows.
- *Climate data assignment of Ankara*: the last group of simulation models are generated by using the same design and thermal parameters of second group, while they are simulated with the climate conditions of Ankara. The purpose of this variation is to observe the relation between different weather conditions and building design parameters in terms of building performance characteristics and future climate conditions. Accordingly, the comparisons between different groups of configuration results have been made after conducting the simulations.

3 Energy and environmental performance analysis results and discussion

In this section, the simulation results for all weather data (2018, 2050s and 2080s) and cities (İzmir and Ankara) are given and discussed. According to the analyses, design decisions about the window features is assumed to be one of the significant issues about building envelope in terms of building energy and environmental performance. The results presented below indicate the effects of WWR (20%, 35%, 40%, 60%, 80%), window orientation (north, south, east, west) and thermal characteristics of windows on annual energy consumption (heating and cooling loads) as well as operational CO_2 emissions of an office building regarding two different climate conditions of İzmir and Ankara. The results of the analyses are given separately for east-west and north-south facades. In addition, these graphs show the changes in annual total heating and cooling loads (kWh/m^2) and annual operational CO_2 emission loads (kgCO_2e/m^2) over the years. The results of the analyses are given in three separate sections as follows:

Firstly, the analysis results of the first simulation group which includes the simulation model of the office building, variations in the design parameters (WWR and building orientation), and İzmir weather data as the climate parameter.

Secondly, the analysis results of the second simulation group including the same case building and climate scenario, while the thermal characteristics of windows are enhanced with the application of windows having 0.9 W/m^{2}K U values.

Thirdly, the analysis results of the third stage of the simulations generated by the same office building model, as well as the same design parameters and thermal characteristics with the second group, while the weather conditions of Ankara are used as the climate parameter.

3.1 Analysis results of WWR value variations

In this chapter, the total annual heating and cooling loads as well as operational CO_2 emissions of the first simulation group under climate change conditions are investigated by the analyses. The results illustrated in Figures 3 and 4 indicate that annual cooling loads increase in accordance with the future climate scenarios, while decreases in annual heating loads are observed accordingly. In the analyses calculated according to 2080s weather data, there is a noticeable difference when compared with the previous years. In this year's configurations, despite the decreases in heating load, considerable increases in the cooling load has significant impacts on the total energy consumptions. Therefore, the effects of global warming are more obvious in 2080s. The energy consumptions of the base model in recent, 2050s and 2080s weather conditions are 52.1, 55.87 and 62.23 kWh/m^2, respectively.

When the analysis results of all the configurations are examined, it has been seen that the lowest energy-consuming configuration is the north facade with a WWR value 20% in weather data of 2018 with 50.48 kWh/m^2. The highest consumption is observed for the south facade with a WWR value 80% in weather data of 2080s with 70.01 kWh/m^2.

It has been seen that, there are not any considerable effects of WWR and window orientation on the annual heating load, depending on relatively smaller areas of facades and relatively less sun exposure. In addition, annual cooling loads increase while the amount of heating energy consumed decreases within time for south and north directions. Besides, the more WWR increases, the more cooling energy is required annually. As seen in the results, annual heating consumption is reduced by increasing WWR for south orientation. This is due to the utilisation of solar energy that enters space through the windows. On the contrary, higher values of WWR for north facade increase annual heating energy consumption, as well. Lastly, according to the results, wider window selection results in greater energy consumption values.

Figure 3 Annual energy consumption and operational CO_2 emissions of WWR value variations (west and east directions) (see online version for colours)

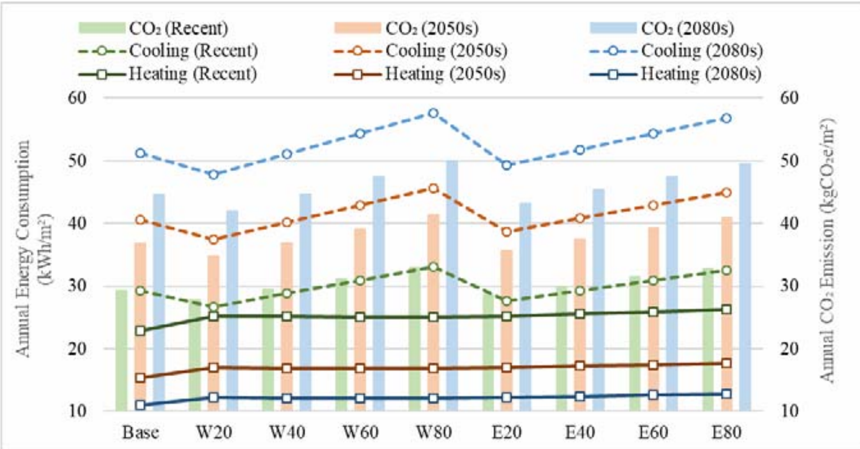
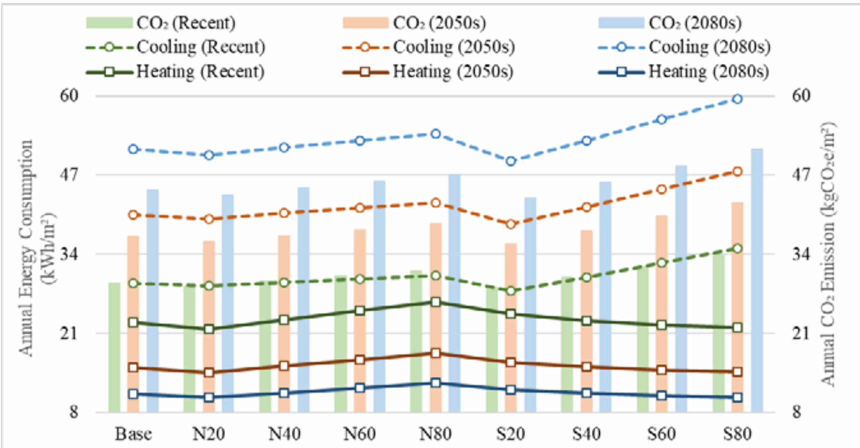


Figure 4 Annual energy consumption and operational CO_2 emissions of WWR value variations (north and south directions) (see online version for colours)



According to the analysis results shown in figures, over the years it seems that carbon emissions in the model office building have increased. Therefore, annual operational CO_2 emission value has reached peak point in 2080s with the value of 51.22 $kgCO_2e/m^2$. The CO_2 emissions of the base model in 2018, 2050s and 2080s are 29.29, 36.77 and 44.52 $kgCO_2e/m^2$, respectively. As reflected in the total load analyses, the effects of global warming are seen more specifically in the scenarios of 2080s.

The lowest emission value is achieved in the west facade with WWR value of 20% in the 2018 weather data configuration with the value of 27.72 $kgCO_2e/m^2$. Also, the highest emission value is seen in the south facade with WWR value of 80% in the 2080s weather data with the value of 51.22 $kgCO_2e/m^2$. Between all configurations, as WWR increases, it appears to cause increases in operational CO_2 emissions, as well.

3.2 Analysis results of window thermal performance improvements

In this simulation group, the total annual heating and cooling loads of models including windows with U value of 0.9 W/m^2K and İzmir as the location of office building are given. Figures 5 and 6 show that decreases in annual total energy consumption were observed as expected, because of the lower U values of windows. Especially, the annual heating load decreased by 20% when compared to 2018 analyses. The energy consumptions of the base model in 2018, 2050s and 2080s are 48.79, 53.44 and 60.08 kWh/m^2, respectively.

The lowest energy consumption results from all simulations are seen again for the north facade with a WWR value of 20% with weather data of 2018 with 47.18 kWh/m^2. In addition, the highest consumption is observed for the west facade configuration with a WWR value 80% with weather data of 2080s with 68.24 kWh/m^2.

It is seen that the changes in north and south facades are more effective in energy consumption than east and west facades. Besides, as the WWR of the south facade increases, it is observed that the annual heating loads decrease and the annual cooling loads increase. However, on the north facade, when the WWR increases, the annual heating and cooling loads increase. Nevertheless, the north facade is the most energy efficient facade between these configurations, because the south facade configurations cause significant increases in the annual cooling loads.

Figure 5 Annual energy consumption and operational CO_2 emissions after window thermal performance improvements (west and east directions) (see online version for colours)

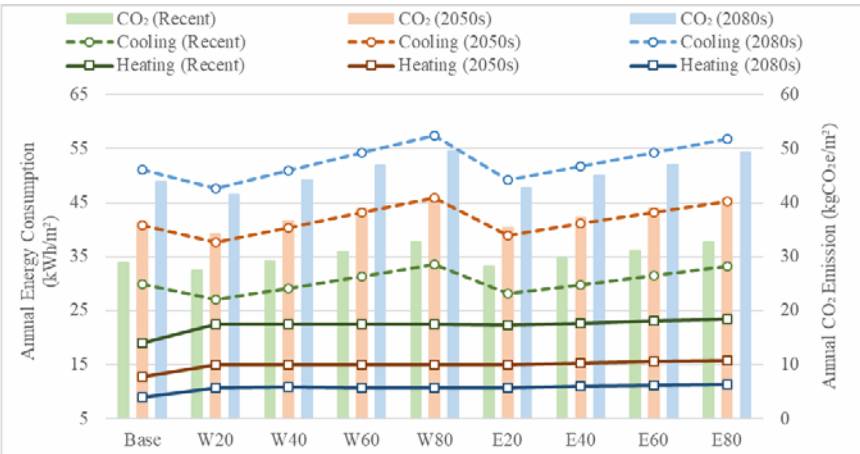
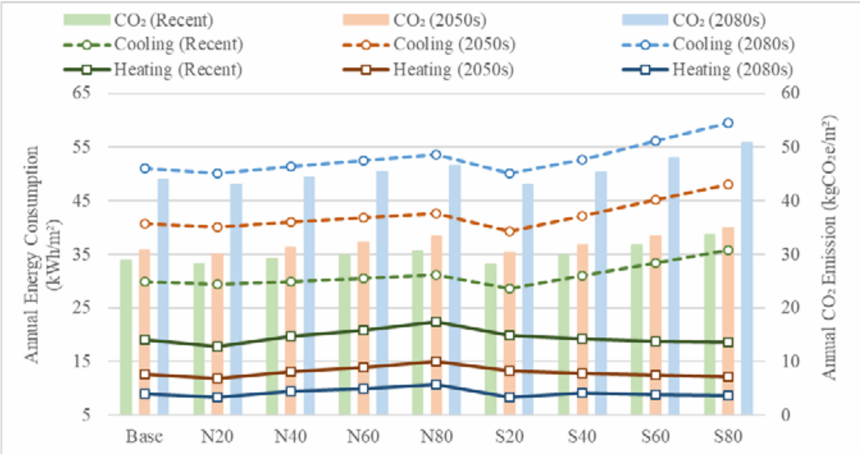


Figure 6 Annual energy consumption and operational CO_2 emissions after window thermal performance improvements (north and south directions) (see online version for colours)



The fact that the annual cooling loads are similar in this group when compared to the first group and this effects the operational CO_2 emission values almost to the same extent. Compared to the 1.6 W/m^{2}K window type analyses, the carbon emission values of this group are slightly lower. The lowest operational CO_2 emission value is achieved in the west facade with WWR value of 20% in the 2018 weather data configuration with the value of 27.32 kgCO_2e/m^2. The highest operational CO_2 emission value is seen in the south facade generated by WWR value of 80% in the 2080s weather data with the value of 50.81 kgCO_2e/m^2.

3.3 Analysis results based on the assignment of climate data of Ankara

In this section, the analysis results of simulations including the office model located in Ankara and the window U value of 0.9 W/m^{2}K are presented. The annual total heating, cooling consumptions and operational CO_2 emission load can be seen in Figures 7 and 8. According to these graphics, as expected, the annual heating energy consumption values decrease, and the annual cooling energy consumption values increase over the years. However, the annual heating load always exceeds the annual cooling load, since Ankara is in a cooler climatic zone than İzmir. The energy consumptions of the base model in 2018, 2050s and 2080s are 79.39, 72.27 and 70.85 kWh/m^2, respectively.

Unlike the other two analysis groups, the lowest energy consumptions are achieved in 2080s weather data. This is due to the fact that, the more annual cooling consumptions increase dramatically, the more annual heating loads decrease, as well. The lowest energy consumption result is collected from the north facade scenario with WWR value of 20% in weather data of 2080s with 68.40 kWh/m^2. The reason of these results is because of the fact that the annual heating load values are more decisive for Ankara and the effects of global warming in 2080s will be greater. Also, it is understood that the selected window type is more effective in cold climates than mild climates.

The changes in the north and south facades give lower energy consumption results than the west and east facades, again. In addition, the annual total energy consumption values in the north and south facades are very close.

Figure 7 Annual energy consumption and operational CO_2 emissions with regard to the climate data of Ankara (west and east directions) (see online version for colours)

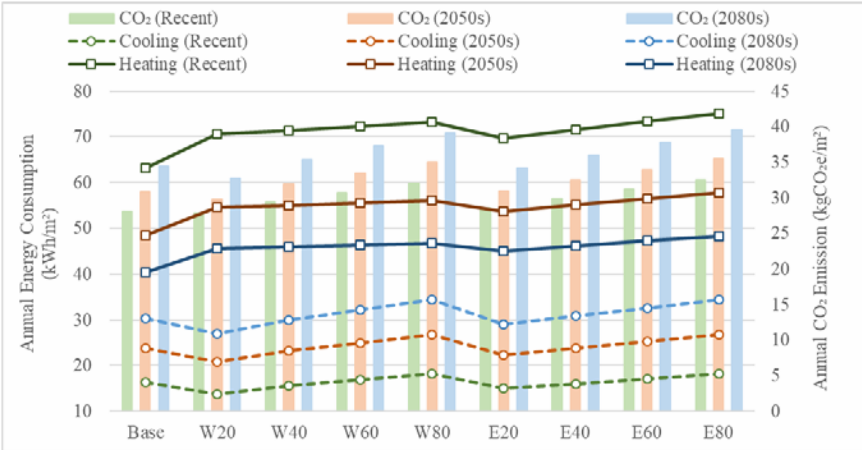
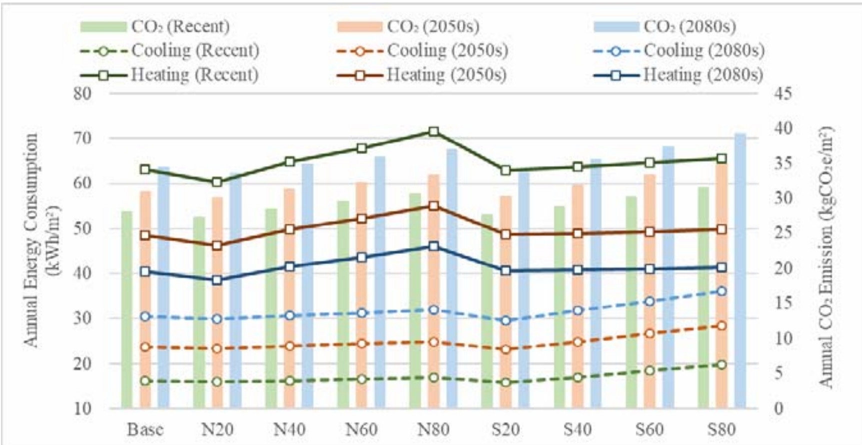


Figure 8 Annual energy consumption and operational CO_2 emissions with regard to the climate data of Ankara (north and south directions) (see online version for colours)



Despite the decreases in the total energy consumption characteristics, the highest operational CO_2 emission values are observed for 2080s weather data simulations. The increases in the annual cooling loads have led to these results despite the decreases in the annual heating loads.

3.4 Discussion

The current study represents the simulation results of several window configuration strategies applied to a reference office building model for different climatic conditions of Turkey by considering the impacts of climate change scenarios. Simulations revealed that, with the increase of WWR the annual heating energy consumption, the annual cooling energy consumption and operational CO_2 emission values increased for west, east and north directions. However, the annual heating consumption is reduced by increasing WWR for south orientation. This is possibly due to the fact that the more transparent surface area increased, the more daylight was transmitted inside the building resulting the interior space to become more heated. Although, the least heating energy consumption value difference between WWR scenarios is observed in west facade variations. On the contrary, it is observed that increasing WWR for north direction cause significant rises in annual heating energy consumption. Namely, when the WWR was increased from 20% to 80% the annual heating energy consumption increased by 33%. However, the annual cooling energy consumption rises in each orientation and WWR scenarios, and the highest impact of WWR on annual cooling energy is observed on south facade configurations by 25%. Besides, the highest operational CO_2 emission value is observed on the south facade with WWR value of 80% in the 2080s weather conditions.

In the test cases investigating the effects of retrofits in thermal characteristics of the windows with respect to U values, the windows with U values of 1.6 W/m^{2}K are transformed into 0.9 W/m^{2}K U values. The rest of the conditions of previous simulations are not changed in order to observe only the impact of different thermal conditions of transparent surfaces on energy and environmental performance of the building with respect to changing climatic conditions within time. The general characteristics for annual energy consumption follow similar patterns with the first group, while considerable decreases in total energy consumption are observed. The changes in WWR of north and south facades are seen to be more effective for reducing energy consumption when compared with east and west facades. Still, the north facade is observed as the optimal and the most efficient façade for modifications, since significant increases in the annual cooling consumptions are occurred. When compared to the previous window thermal properties, the operational CO_2 emission values are slightly lower. The highest operational CO_2 emission value is observed in the south facade with WWR value of 80% in the 2080s weather data.

Then, the performances of proposed window type and the climatic conditions of Ankara were analysed while design parameters were used as the same with previous configurations. The aim was to establish how the proposed window type would perform in another location (Ankara, Turkey) with cold-dry climatic condition in contrast to previous simulations carried out according to hot-humid climatic settings of İzmir, Turkey. From the simulated results it is observed that, the annual heating energy consumption decreases, and the annual cooling energy consumption increases over the years. Nevertheless, the annual heating loads always exceed the annual cooling loads, since Ankara is a city located in a cooler climatic zone than İzmir. Interestingly, the lowest energy consumption values are achieved in 2080s weather data, unlike previous configurations. This is caused by the huge amounts of increases in annual cooling consumptions while the annual cooling loads are also decreased as the same way. Besides, the results indicate that, the annual heating consumption characteristics are more decisive for the buildings located in Ankara and the effects of global warming in 2080s would be greater, as well. In addition, it is observed from the analyses that the selected window type is more effective in cold climates than mild climates. Despite the decreases in the total energy consumption, the highest operational CO_2 emission values are seen in 2080s weather data. The reason is the higher impacts of increases in the annual cooling consumptions rather than the decreases in the annual heating consumptions.

4 Conclusions

This study evaluates the influence of various configurations in WWR, window orientations and window components as well as different climatic conditions regarding an office building.

It can be concluded from the point of energy conservation, the modifications in window thermal properties offer lower amounts of energy consumption. Besides, it shows better performance when applied to buildings located in cold-dry climatic conditions rather than hot and humid climates in terms of annual energy consumption and operational CO_2 emission characteristics of the building. Though, the annual energy consumption and operational CO_2 emission values increase over the years, as expected. However, the highest impact of climate change conditions is observed on the energy and environmental performance characteristics of the south facade configurations. Besides, the buildings located in hot and humid climatic regions would be more affected by climatic changes than colder climatic regions due to drastic increases in cooling demands.

On the other hand, the scope of this work is limited to the evaluation of building components for energy and environmental performance, and dependant on externally obtained climatic data. Accordingly, future work would consider finding optimal solutions in terms of studied parameters as well as focusing on acquiring the validated weather data for İzmir and Ankara.

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