Influence of Window Parameters on the Thermal Performance of Office Rooms in Different Climate Zones of Turkey

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Abstract- Window and façade characteristics significantly influence the energy consumption of office buildings. This paper investigates the influence of window configuration on its energy performance regarding shading levels, orientation, geometrical characteristics, and thermo-physical properties. A series of simulations of two common type of office room models were conducted with changing parameters such as the window-to-wall ratio of the façade, total solar energy transmittance value of the glazing, as well as shading levels regarding orientations. The energy simulations were performed using TRNSYS software for the climatic conditions of Istanbul, Ankara, Izmir, and Hakkari. It was found that appropriate selection of windows and shading devices regarding climatic conditions would lead to a significant reduction of the annual energy consumption and greenhouse gas emissions. The recommendations presented in this paper can be applied to any location around the world that has similar climatic conditions with the cities studied in this work.

Keywords Window, Thermal performance, shading, total solar energy transmittance, heating, cooling.

1. Introduction

Global warming, environmental pollution and the extinction of fossil fuels are one of the main struggles of humanity. Buildings consume nearly 40% of the world's energy and emit 20% of the total CO_2 emissions [1], [2]. The main purposes of buildings are provide occupant comfort, acoustic comfort and air quality, economically, efficiently and ecologically [3]. In current environment, where energy efficiency becomes crucial, the efficient use of existing sources and energy-efficient designs in building technology has been increased [4]. Windows play a crucial role in energy consumption and visual comfort of buildings. Determining their areas, features and proportions is part of fundamental early design stage decisions, and it is hard to change later [5]. Regarding energy balance, windows can either decrease or increase energy loads of a building through solar heat gains or conduction heat losses, respectively [6]. Even though windows have greater thermal transmittance value than the walls, heat gains through solar radiation from windows with larger areas might decrease the annual heating load of the building while increasing the annual cooling load. The energy transfer through windows depends on many parameters such as climatic conditions, shading levels, orientation, frame material, glazing type, area of the glazing and many other factors [7]. The selection of the glazing types must be made by a detailed analysis of their impact according to the geographical location and respective climate conditions [8].

It is difficult to estimate the actual thermal performance of buildings based on real observations [9]. Nowadays, a wide variety of building energy simulation programs have been used by building designers to find the best scenario for reducing heating and cooling loads of the buildings during the early design stage. TRNSYS is a simulation program for transient analysis which employs an open modular structure that provides the user to create a representative model of a physical system. Type56 and TRNBuild components allow modeling the thermal behavior of a building divided into thermal zones [10]. Each thermal zone is characterised by a number of properties defined by the user such as floor area, window area, U-value of the building components etc. [11]. The user can also define the room setpoint temperature, the cooling, and heating power, and the dehumidification of the air within the zone based on a schedule

Several studies have already focused on thermal performances of windows with using dynamic simulation tools. In a previous study, Wen et al. (2017) conducted a study to create maps of recommended window-to-wall ratios (WWR) in Japan [12]. Five design conditions investigated are lighting power density, climate, window orientation, internal gains, and building scale. They used Energy Plus software for integrated thermal and lighting simulations. They presented influences of WWR on the CO_2 emissions regarding cooling, heating, and lighting energy loads for representative Japanese climates of Sapporo, Tokyo and Naha. Amaral et al. (2016) conducted a parametric study based on glazing type, orientation, size and shadow effect on the thermal performance of a reference room located in Coimbra, Portugal [8]. An evaluation and optimization procedure was carried out to obtain information on the thermal performance of the reference room in an annual, seasonal and quadrant basis. For each window type, the room's thermal performance assessment was carried out for every orientation, and optimum values of WWR are presented. Alghoul et al. (2017) investigated the influence of window-to-wall ratio (WWR), and window orientation on cooling, heating and total energy consumption by using Energy Plus software [13]. They analysed the thermal performance of a small office building located in Tripoli, Libya, with changing WWR between 0 and 0.9 and orientation in steps of 45˚. Their results show that with rising WWR, annual cooling energy demand increases while annual heating load decreases. When rising the WWR in southern walls, cooling energy consumption increases significantly while heating load decreases to zero due to passive solar heating. Goia (2016) investigated optimal window-to-wall ratio in office buildings for different European climates [14]. With integrated thermal and lighting simulations, the optimal WWR for each main orientation was found by the author. The results of the article indicate that even though ideal values of WWR vary in each climate and orientation, most ideal values can be found in a narrow range ($0.30<WWR<0.45$). Gasparella et al. (2011), investigated the impact of different kinds of windows on winter and summer energy needs of a well-insulated residential building with using the climatic data of Paris, Milan, Nice and Rome to identify the most influencing parameters [15]. The results of the study indicate that the use of large glazing improves winter performance, especially for the south orientation. Also, in winter the use of windows with high total solar energy transmittance value is more beneficial, while in summer the use of glazing with high total solar energy transmittance value considerably increases the cooling load of the building. Persson et al. (2006) conducted a study to investigate how decreasing the window size facing south and increasing the window size facing north in low energy houses would influence energy consumption with using the climatic data of Gothenburg, Sweden [16]. They used a dynamic simulation tool named DEROB-LTH. The results of the study to minimize the cooling requirement indicate that it is better to reduce window glazing area toward the south to 0, but it is not beneficial regarding visual comfort. As a result, having larger windows towards the north while keeping the southern façade WWR at a minimum rate is recommended. Bikas et al. (2014) proposed a new rating system for assessing the cooling performance of windows [17]. They defined the climatic zone of Europe and conducted a dynamic simulation of energy loads of a reference building for 15 different cities located on defined climatic zones. Window sizes and their orientations, as well as, window properties and frame fractions were studied for each climatic zone, and a window rating scheme was presented. Poirazis et al. (2008) investigated energy efficiency of highly glazed buildings and carried out a dynamic simulation of a reference building in Sweden with changing the window-to-wall ratio, type of windows, type and size of the shading devices, building's orientation, etc. [18]. Main conclusions of the paper indicate that low total solar energy transmittance of the windows and externally placed shading devices have a great impact on the cooling load and they are very efficient for decreasing annual cooling energy consumption. Eskin and Turkmen (2008) investigated the energy requirements of an office building for different climates of Turkey [19]. They carried out the simulations with using Energy Plus software. In their study, first, they validated the simulation program by comparing the output results of the software with the results of the monitored building. Then, they investigated the effect of the parameters such as insulation thickness, window area, aspect ratio, thermal properties of glazing products, colour of external walls, shading levels, ventilation rates, and outdoor air control strategies. Results of the article point out that annual cooling energy requirement and annual total energy requirement of the office buildings increase noticeably with high quantities of glazing as compared to the buildings with lower glazing area for all climates. Inanici and Demirbilek (2000) investigated the effect of building aspect ratio and south window sizes on annual energy consumption of residential buildings [20]. They used the simulation software SUNCODE-PC for parametric analysis for the climatic data of five cities of Turkey: Erzurum, Ankara, Diyarbakır, Izmir and Antalya. According to the findings of their study, changing the window size of the south-facing façade significantly affects the total energy demand. In Erzurum and Ankara, total energy loads decrease as south window size increases. As the cooling load is more important in determining the total energy demand in Diyarbakır, Antalya and Izmir, the total load increases as south window size increases. Summary of the previous studies is presented in Table 1.

From the literature survey, it was seen that, although there are studies regarding thermal performance of windows, previous researches mainly focused on the impact of various parameters on the thermal performance of windows with only considering heating load or cooling load. To the best of authors' knowledge, there are not any publications that tackle all different Turkish climate zones and this is the first comprehensive study of the impact of window sizes, glazing types, shading levels, orientations on both heating and cooling energy consumption of different office room models, regarding various climate zones of Turkey. The aim of this study is to conduct an investigation of the effect of parameters such as (i) window to wall ratio (WWR), (ii) total solar energy transmittance (g values) of the glazing products, (iii) shading level, (i□) orientation, (□) climatic conditions on annual heating and cooling load of two different office units with using a dynamic simulation tool.

Table 1. Climatic conditions, investigated parameters and used simulation program of some of the previous studies

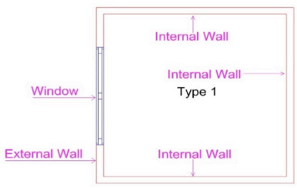
References	Climate locations	Investigated parameters	Notes	Simulation Program
Bikas et al. **[17]**	14 different cities in Europe	Window-to-wall ratio; U value of the window; g value of the glazing; Frame fraction; Orientation; Shading levels	Only cooling load was considered	EnergyPlus
Gasparella et al. **[15]**	Paris, Milan, Nice, Rome	U value of the window ; Window-to-floor ratio; Orientation; Internal gain levels; Shading levels	Heating and cooling loads were considered	TRNSYS
Amaral et al. **[8]**	Coimbra	Shading levels; Window-to-floor ratio Orientation; U value of the window	Heating and cooling loads were considered	EnergyPlus
Wen et al. **[12]**	Tokyo, Sapporo, Naha	Window-to-wall ratio; Orientation	Heating, cooling and lighting loads were considered	EnergyPlus
Inanici and Demirbilek **[20]**	Erzurum, Ankara, Diyarbakır, Izmir, Antalya	Window-to-wall ratio; Building aspect ratio	Heating and cooling loads were considered	SUNCODE-PC
Hassouneh et al. **[7]**	Amman	U value of the window; g value of the glazing; Orientation ; Window-to-wall ratio	Only heating load was considered	Self-developed
Lee et al. **[21]**	Manila, Taipei, Shangai, Seoul, Sapporo	U value of the window; g value of the glazing Orientation; Window-to-wall ratio	Heating, cooling and lighting loads were considered	COMFEN
Alghoul et al. **[13]**	Tripoli	Window-to-wall ratio; Orientation	Heating and cooling loads were considered	Energy Plus
Jaber and Ajib **[22]**	Amman, Aqaba, Berlin	Orientation; Window-to-wall ratio; U value of the window; g value of the glazing	Heating and cooling loads were considered	TRNSYS
Ochoa et al. **[5]**	Amsterdam	Window-to-wall ratio; Orientation	Heating, cooling and lighting loads were considered	Energy Plus
Ebrahimpour and Maerefat **[23]**	Tehran	U value of the window; g value of the glazing; Different overhang and side fin configurations ; Orientations	Heating and cooling loads were considered	Energy Plus
Eskin and Turkmen, **[19]**	Ankara, Istanbul, Izmir, Antalya	Window-to-wall ratio; U value of the window; g value of the glazing; Shading devices	Heating and cooling loads were considered	Energy Plus
Pino et al.**[24]**	Santiago	Shading devices; U value of the window; g value of the glazing; Orientations	Heating and cooling loads were considered. Also daylight analysis was conducted .	EDSLTAS and DAYSIM

Four different cities were selected to serve as a representative one with each climate zone of Turkey. Izmir and Istanbul correspond to the first and second climatic zones while Ankara and Hakkari correspond to third and fourth climatic zones respectively. Therefore, simulations were carried out for the climatic data of the selected cities, with using the Meteonorm database of TRNSYS 17. Since space heating and cooling of office buildings accounted for a large fraction of global energy consumption, two very common office room types were selected as reference models. The overall aim of this article is to propose a methodology for adopting energy efficient window solutions with considering the climatic conditions of office buildings.

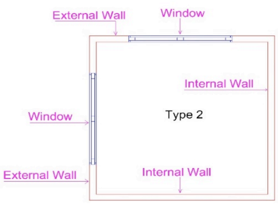
2. Methodology

2.1 Description of the reference zones

Parametric evaluation is carried out for two reference office rooms. Plans of the office rooms are shown in Figure 1. Office buildings consume large amounts of energy, and they have specific and homogenous energy needs. Therefore it is easier to study and apply conversion measures [9]. The main reason for selecting two different models was to investigate the impact of windows on thermal performance of commonly used office room configurations worldwide. Both rooms have the same dimensions: 5 m (l), 5m (w), 3m (h). Type 1 room is a typical office room with one external wall and window exposed to the outside environment and located between two corner rooms, while Type 2 room is located at the corner of the building and has two external walls facing two different orientations. The rooms have 25 m^2 floor area. The windows are considered as located at the centre of each external wall of the rooms, internal walls, roof and ground are assumed to be adiabatic. External walls are insulated, and properties of the building components are presented in Table 2. Argon filled, low-E, a double glazed window is selected (U_w=1.3 W/m^2.K) for the reference rooms which is appropriate to use for all climatic zones according to Turkish standards and only total solar energy transmittance (g value) of the glazing is a variable parameter. For occupancy schedule, it was assumed that building is only occupied during the weekdays from 08:00 to 18:00. The heating temperature set-points were assumed equal to 22˚C during the occupied hours and 18˚C during non-occupied hours. Cooling temperature set point was determined as 26 ˚C. Occupant density was considered equal to 0.1 occupants/m^2 and specific lighting gains were determined as 10 W/m^2 during occupied hours if the total horizontal radiation level is lower than 120 W/m^2 (After creating the temperature set-points of the zone, it is calculated automatically in TRNSYS with the use of solar radiation level of the location). During the operating time, infiltration and ventilation rates were considered as 0.5 ACH and 1.5 ACH respectively. All of the simulation case alternatives are presented in Table 3.



(a)



(b)

Figure 1. The layout of the reference office buildings:

a) Type 1 office room b) Type 2 office room

2.2 Parameters

The reference office rooms were modeled with using well-known simulation software TRNSYS. TRNBuild, a component of the TRNSYS simulation software was used to generate the building load profile.

The TS 825 Turkish Building Code divides Turkey into four different climatic zones depending on average heating degree-days [24], [25]. According to this obligatory standard, maximum overall heat transfer coefficients (U values) of the building components are defined for each climate zone (Table 4). In this study, four case locations were selected, which represents different climate zones of Turkey. Istanbul has a moderate climate with hot summer and cold winter. Hakkari has a snow climate with dry summer and snowy very cold winter. Ankara has a cold and dry climate with a dry summer. And Izmir has Mediterranean climate with hot and sunny summer and short winter.

Table 2. Selected properties of the building materials

Window to wall ratio in each façade	0.30
Frame to window ratio	0.15
U value of the window	1.3 W/m^2.˚C
g Value of the glazing	0.591
U value of the external wall	0.339 W/m^2.˚C
U value of the window frame	2.27 W/m^2.K

Degree day method is a very common method for assessing and classifying climate regions with common climatic characteristics [17]. The average cooling degree day (CDD) and heating degree day (HDD) values between the years 1975-2005, provided by the Turkish State Meteorological Service are presented in Figure 2 [26]. For heating, heating degree-days can be calculated according to Eq. (1), and for cooling, cooling degree-days can be calculated according to Eq. (2, where T_b is the base temperature and, T_m is the daily mean outdoor temperature, and the plus sign above the parentheses indicates that only positive values are to be counted, [27].

[illegible] (1)

$$CDD = \sum_{days} (T_m - T_b)^{+} \quad (2)$$

The amounts of heating degree-days for selected cities were calculated at a base temperature of 18˚C, and for cooling degree-days, the base temperature of 22 ˚C was found appropriate. Bikas et al. (2014), classified European cities into zones according to the region's heating and cooling degree days [17]. According to their study, the value of 2500 HDD was considered as the limit, above which a climate could be classified as heating dominating climate zone, while the value of 500 CDD was considered as the limit, above which the climate can be classified as cooling dominated climate zone. Based on this information, Hakkari and Ankara can be classified as heating dominated climate regions since average heating degree-days are 2604 for Ankara and 3363 for Hakkari as presented in figure 2. Izmir can be classified as a cooling dominated climate region as average cooling degree days of Izmir is given 517, in figure 2. Istanbul has neither heating nor cooling dominated climate tendency with 1937 heating degree-days and 44 cooling degree-days. As a result, it can be defined as a temperate climate.

The geometrical characteristics (WWR), thermo-physical properties (solar transmittance, g-value) of the glazing, orientation and shading factors were taken into account as variable parameters. Eleven window-to-wall area ratios were investigated with increasing window area from 0 to 99 % for different orientations. To investigate the influence of shading on annual energy consumption of the reference rooms, different levels of shading were considered, varying from unshaded conditions to heavily shaded conditions (shading factor 0-75 %), with a step of 25 %, [17]. As regards to different thermal properties, window glazing with varying g values was studied while keeping the U value as constant (1.3 W/m^2.°C). The selected g values of the window represented both high (0.624), low (0.212) and medium values of the solar transmittance of the glazing and presented in Table 4. In total, 640 alternative cases were simulated [2 unit types*4 climates*4 orientations*(11 WWRs + 5 g-values + 4 shading levels)]. The energy consumption values are presented as a ratio of annual values per meter square of the total external wall area of the reference unit [13]. Only thermal performance of the reference room is considered, while other parameters such as visual comfort and lighting conditions are not taken into account in this study.

2.3 Calculation methods

The methodology used in the present study follows a procedure where in the first stage, Type 1 and Type 2 reference rooms were created with a window placed in each exterior wall. Then, the window-to-wall ratio of the rooms changed from 0 to 100 per cent, linearly in all regions. Then, reference rooms rotated in such a way that exterior walls faced one of the four cardinal orientations. A parametric evaluation was made by incrementally simulating every window size (from no window case to fully glazed case) regarding four cardinal orientations. In total, 352 configurations were obtained varying WWR of office units. Later, figures were created to see the reference room's energy performance based on the simulation results of all cases. In the second case, total solar energy transmittance value (g value) of five different glazing types was compared in terms of annual energy consumption regarding orientations. In the third case, the influence of external shading factor of the glazing regarding orientations on overall energy consumption was investigated.

The heat transfer between a window and outside and inside environment can be described by conduction, convection and radiation mechanisms. Convection heat flux to a zone due to the difference between the indoor and outdoor temperatures can be expressed as [10]:

$$Q_i = Q_{inf,i} + Q_{vent,i} + Q_{g,c,i} + Q_{cplg,i} \quad (3)$$

The infiltration gains expressed as below:

$$Q_{inf,i} = V.\rho.c_p.\,(T_{outside} - T_{air}) \quad (4)$$

$Q_{vent,i}$ is the ventilation gains, $Q_{g,c,i}$ and $Q_{cplg,i}$ are the internal convective gains (by people, equipment, illumination etc.) and gains due to connective air from boundary condition, respectively.

$$Q_{vent,i} = V.\rho.c_p.\,(T_{ventilation,i} - T_{air}) \quad (5)$$

Table 3. Thermo-physical and geometrical parameters of the examined window type

	U window	g-glazing	FF	WWR	SHC
	W/m^2°C	-	%	%	%
Case 1	1.3	0.591	15	**0**	0
Case 1	1.3	0.591	15	**10**	0
Case 1	1.3	0.591	15	**20**	0
Case 1	1.3	0.591	15	**30**	0
Case 1	1.3	0.591	15	**40**	0
Case 1	1.3	0.591	15	**50**	0
Case 1	1.3	0.591	15	**60**	0
Case 1	1.3	0.591	15	**70**	0
Case 1	1.3	0.591	15	**80**	0
Case 1	1.3	0.591	15	**90**	0
Case 1	1.3	0.591	15	**100**	0
Case 2	1.3	**0.212**	15	30	0
Case 2	1.3	**0.298**	15	30	0
Case 2	1.3	**0.397**	15	30	0
Case 2	1.3	**0.591**	15	30	0
Case 2	1.3	**0.624**	15	30	0
Case 3	1.3	0.591	15	30	**0**
Case 3	1.3	0.591	15	30	**25**
Case 3	1.3	0.591	15	30	**50**
Case 3	1.3	0.591	15	30	**75**

Where, ρ is the air density (kg/m^3), c_p is the air specific heat (kJ/kg.K), V is the air flow rate (m^3/s). Radiative heat, flows to the walls and windows of the zone is as presented, [10]:

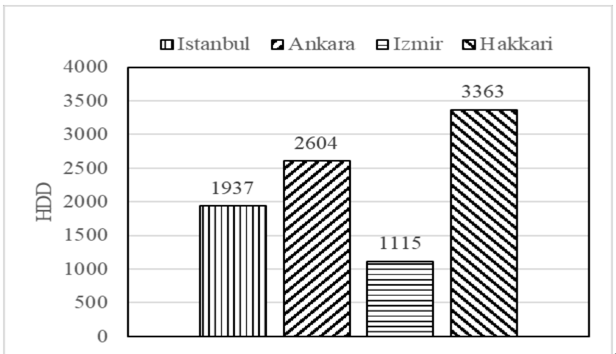
$$Q_{r,wi} = Q_{g,r,i,wi} + Q_{sol,wi} + Q_{long,wi} + Q_{wall\text{-}gain} \quad (6)$$

Where, $Q_{r,wi}$ is the radiative gains for the wall surface temperature node, $Q_{g,r,i,wi}$ is the radiative air node internal gains received by the wall, $Q_{sol,wi}$ is the solar gains through the zone windows received by walls, $Q_{long,wi}$ is the long wave radiation exchange between this wall and other walls and windows, $Q_{wall\text{-}gain}$ is the user-specified heat flow to the wall or window surface, all in kJ/h [10].

Figure 3, presents the thermal behavior of a wall or window and here $S_{s,i}$ and $S_{s,o}$ represent radiation heat flux absorbed at the inside and outside surfaces, $q_{r,s,i}$ and $q_{r,s,o}$ represent net radiative heat transfer with all surfaces within the zone and net radiative heat transfer with all surfaces in view of the outside surface, $q_{s,i}$ and $q_{s,o}$ represent conduction heat flux from the wall at the inside surface and into the wall at the outside surface, $q_{c,s,i}$ and $q_{c,s,o}$ represent convection heat fluxes from the inside surface to the air and to the outside surface from the ambient, $T_{s,i}$ and $T_{s,o}$ represents inside and outside surface temperatures, respectively, [10].

Table 4. Turkish standards, maximum U requirements for different climatic zones

TS 825 Climate Zone	1	2	3	4
Selected city	İzmir	İstanbul	Ankara	Hakkari
Latitude	38°42’N	41°00’N	39°93’N	37°44’N
Longitude	27°14’E	28°97’E	32°85’E	43°74’E
Altitude (Elevation)	29 m	40 m	891 m	1728 m
U Outwall [W/m^2.K]	0.7	0.6	0.5	0.4
U Roof [W/m^2.K]	0.45	0.4	0.3	0.25
U Ground [W/m^2.K]	0.7	0.6	0.45	0.4
U Window [W/m^2.K]	2.4	2.4	2.4	2.4



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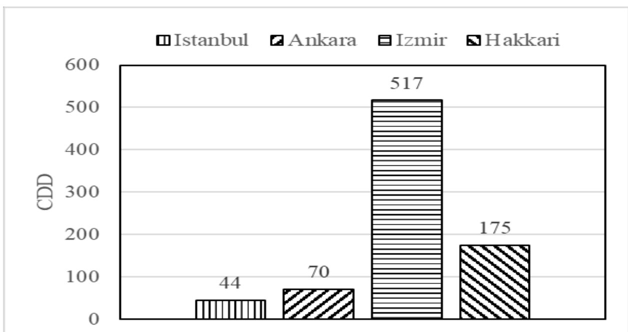

(b)

Figure 2. Average Heating and Cooling Degree Days of four cities, between 1975-2005: a) HDD ; b) CDD.

The optimal WWR corresponds to the minimum value of total annual energy consumption:

$$Q_T=Q_C+Q_H \quad (7)$$

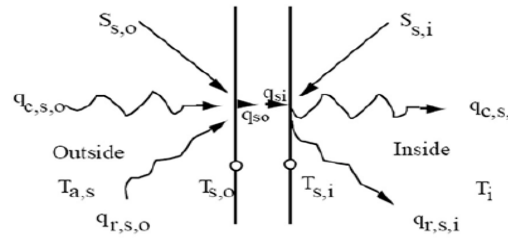

Figure 3. Surface heat fluxes and temperatures of a wall or window [9]

Where Q_C, Q_H are total annual energy consumption for heating and cooling, respectively. Type 56 multi-zone model was used to simulate the building. Meteonorm weather file that includes radiation and temperature data was used. Results of the analysis given as annual heating and cooling load per external wall area of the room (kWh/m^2).

3. Results and Discussion

3.1. Contribution of WWR on annual heating and cooling loads

Window-to-wall ratio (WWR) is an important parameter in building’s annual energy consumption. The simulations were performed to investigate the effects of WWR on annual energy demands. Eleven window to wall area ratio have been studied from no window case (WWR=0%) to fully glazed case (WWR=100%). This procedure was repeated for each orientation since office units facing different orientations may have different optimal WWR values [14]. Figure 4 and 5 show the impact of window size variations in Type 1 office room facing four orientations on annual heating and cooling energy consumptions. In most cases, annual heating energy demand decreases with rising WWR. It is shown that less energy is needed for heating if the south oriented room has a larger window area until it reaches a minimum value (optimum WWR) [16]. After the WWR reaches and exceeds the optimum value, heating load starts increasing.

Regarding heating energy consumption, increasing the WWR of south orientation is the most beneficial strategy for all climate zones. For heating-dominated climates, the optimum window size for Type 1 room for the south orientation is 50% during the heating season. In cooling-dominated and temperate climates, the optimum window proportion is 40% for south facing rooms regarding only the heating season. In Izmir, increasing WWR of the south oriented room from 0 to 40% decreases annual heating load around 85%.

This tendency can also be observed in heating-dominated climates. In Hakkari, increasing the WWR of south-facing orientation from 0 to 40% contributes a 65% decrease in annual heating load of the office unit. This is because of the utilization of solar energy that enters the space through the window, and it contributes to the reduction of the annual heating load for the building [13].

In contrast, with rising WWR of north oriented room, annual heating load also increases. This tendency is more obvious in cities located in heating-dominated climate zone like Hakkari and Ankara. This can be explained as in colder regions solar radiation levels are very low especially regarding north orientation. In addition, despite the fact that selected window type is double glazed, it still has greater total heat transfer coefficient than the external walls.

Similar to the findings of Hee et al. (2015), [29], results of the present study show that increasing WWR of the north facing room has a negative impact in all regions on heating energy consumption, therefore, it is not advisable. Regarding only heating energy consumption, least energy use was observed at 50% WWR for the east-facing room in all climate zones, while 60% WWR for the west-facing room in cooling-dominated climate zone and 50% for the west-facing room in other zones.

In Figure 5 annual cooling load of Type 1 room with changing WWR is presented. Conversely, increasing WWR causes an increase in cooling load for all orientations regardless of the climate zones. As the window size gets bigger, cooling energy load increases significantly. Results show that south-oriented rooms in cooling-dominated climate zone has the greatest energy consumption during the cooling season. With considering the risk of overheating, keeping the WWR as low as possible is recommended for south-oriented rooms. However, window sizes cannot be reduced without considering lighting energy consumption and visual comfort [5]. Due to lower levels of solar radiation, in north-oriented rooms, increasing the window size has less influence on annual cooling load for all climate zones. It is worth highlighting that, the cooling load increases almost linearly with rising values of WWR for east and west orientations in all regions. In figure 6 and 7 annual heating and cooling loads of Type 2 office room as a function of WWR is presented. Similarly to the results of Type 1 room, annual heating and cooling demands present different trends with rising WWR. The simulation results of heating energy demand as a function of WWR reveals that north + west and north + east facing rooms have the greatest energy consumption values when compared to rooms facing other orientations for all climate zones (Fig.6). It is worth highlighting that, for north + east and north + west oriented rooms, increasing the WWR above 20 % is not recommended for heating-dominated climates in terms of energy consumption during the heating season. It is shown that, passive solar heating is possible for south + east and south + west oriented rooms.

Simulation results of the Type 2 room located in the heating-dominated climate zone shows that increasing the WWR of south + east and south + west façades' from 0 to 40% can contribute to a 50% decrease in annual heating energy consumption. It is worth noting that, as it can be seen from Fig. 6, due to the bigger difference between inside and outside temperatures, the influence of the glazing area on annual heating energy consumption is more obvious in the heating-dominated climate zone.

In Figure 7, annual cooling load of Type 2 room with changing WWR is presented. As can be seen, increasing the glazed area facing south + west and south + east orientations increases the annual cooling load significantly in all climate zones. The cooling energy demands of north + west and north + east oriented rooms are slightly lower than other directions. South + west oriented, fully-glazed room located in Izmir has the greatest energy demand during the cooling season, while, north + east oriented, no-window room located in Ankara has the lowest energy demand.

Since increasing WWR, decreases the annual heating load but at the same time increases the cooling load in most cases, optimal WWR values for the climate zones can't be decided by considering only one of them, and it should be considered both at the same time and see the impact of varying WWR on total annual load of the reference units. Therefore, in addition to analyzing windows' performance on a seasonal basis, the results for the effects of WWR on CO_2 emissions corresponding to annual energy consumption were also obtained and presented below. In order to calculate CO_2 emissions regarding annual energy load, average CO_2 marginal emission rate of the year 2016 data was considered. According to this data provided by the U.S Environmental Protection Agency, 7.44×10^{-4} metric tons of CO_2 emissions were emitted in order to utilize per kWh of electricity [30].

Fig.8 shows the effects of WWR on CO_2 emissions corresponding to annual heating and cooling energy use in Type 1 room located in all climate zones. Similar tendencies of increase of CO_2 emissions with increasing window size can be observed in cooling-dominated, heating-dominated and temperate climate zones regarding all orientations but in different magnitudes. Fully-glazed, south-oriented room located in cooling-dominated climate zone causes the greatest amount of CO_2 emissions, while, south-oriented, no-window room located in cooling-dominated climate zone emits the lowest amount of CO_2 emissions annually. In all climate zones, CO_2 emissions calculated for north-oriented rooms is much lower than that of western-eastern and southern oriented models. Between north-oriented rooms located in all climate zones, emissions for Hakkari has the greatest value. The results show that, office buildings with smaller WWR will be more energy efficient regarding all climate zones.

Fig.9 shows the effects of WWR on CO_2 emissions corresponding to annual heating and cooling energy use in Type 2 room for all climate zones. As it can be seen from the figure, all models show tendencies of increase of CO_2 emissions with greater window area for the south + east, south + west, north + east and north + west orientations but in different magnitudes.

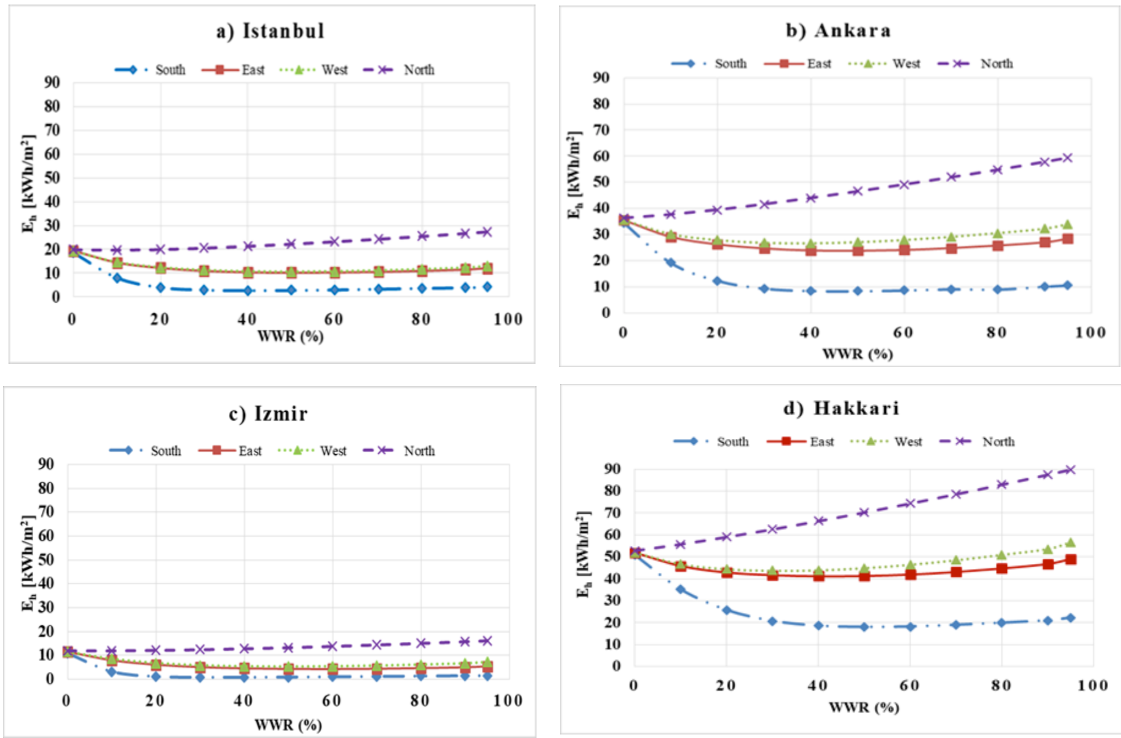

Figure 4. Annual heating load (E_h) of Type 1 room with changing WWR: a)Istanbul b) Ankara c) Izmir d) Hakkari

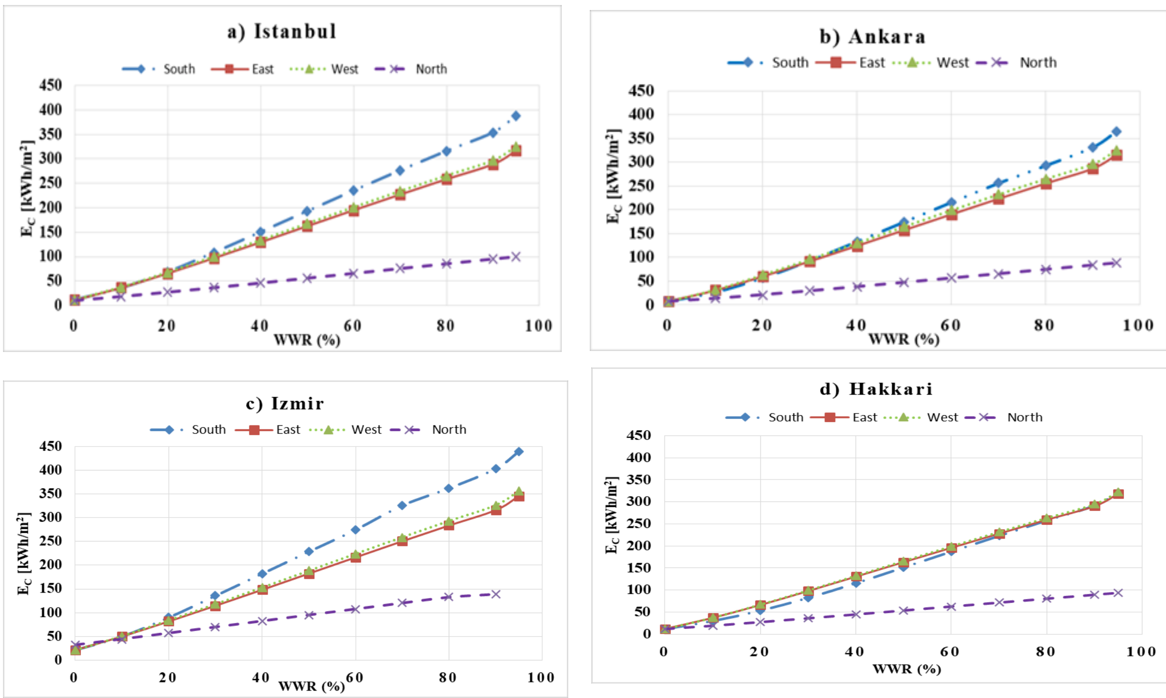

Figure 5. Annual cooling load (E_c) of Type 1 room with changing WWR: a)Istanbul b) Ankara c) Izmir d) Hakkari

Between all models, fully-glazed, south + east and south + west oriented rooms located in cooling-dominated climate zone show the worst behavior in terms of greenhouse gas emissions due to overheating. However, when only north + east and north + faced rooms are considered, north + west facing corner office model located in Hakkari province shows the worse behavior. It is possible to conclude that, in terms of total energy load, large glazing areas facing north significantly increases winter load of the rooms located in heating dominated climate zone due to heat losses and insufficient access to solar gains.

3.2 Contribution of total solar transmittance (g value) of glazing on annual heating and cooling loads

In the second case, the U-value of the window and WWR of all façades remained the same, while total solar energy transmittance (g-value) increased from 0.212 to 0.624 to understand its influence on the annual heating and cooling loads.

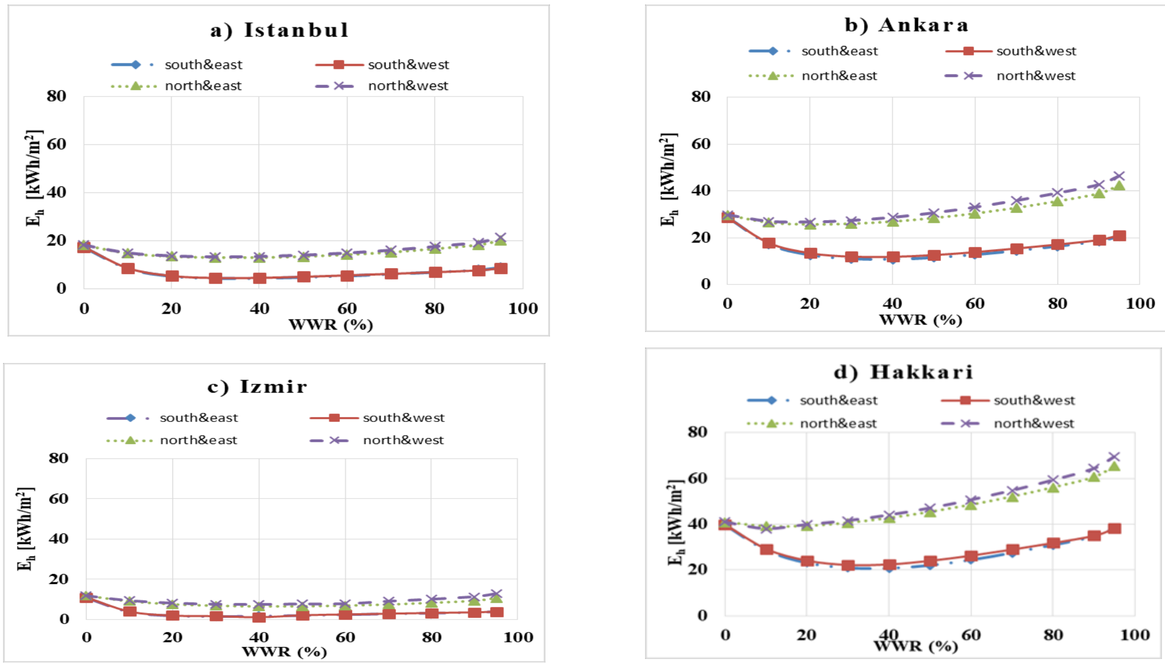

Fig.6. Annual heating load (E_h) of Type 2 room with changing WWR: a)Istanbul b) Ankara c) Izmir d) Hakkari

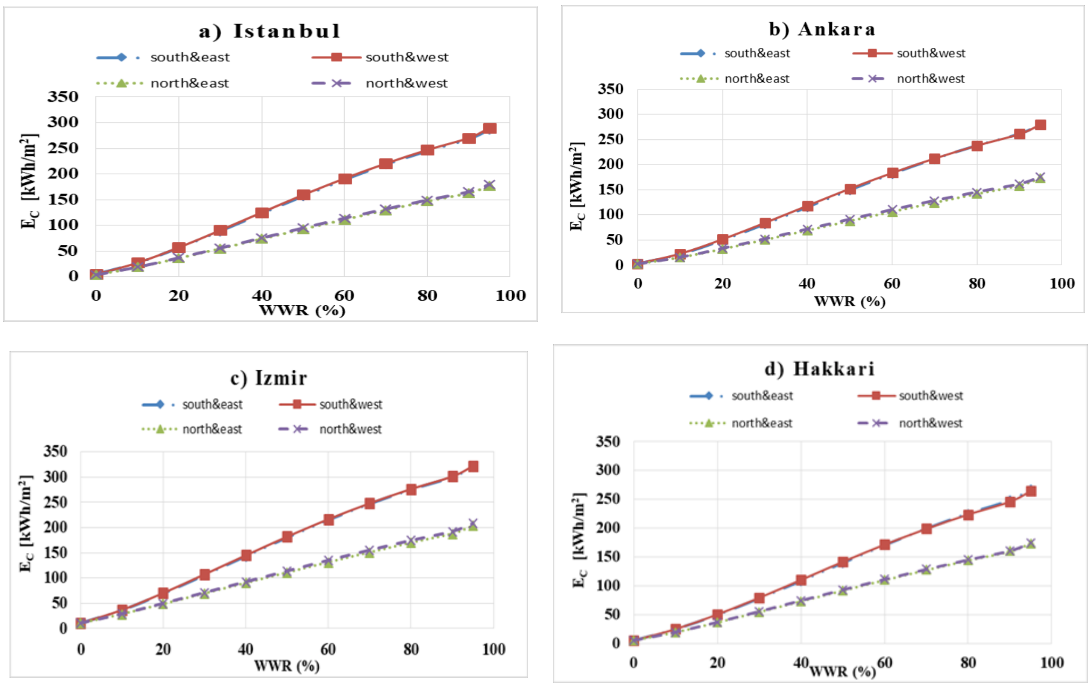

Fig.7. Annual cooling load (E_c) of Type 2 room with changing WWR: a)Istanbul b) Ankara c) Izmir d) Hakkari

Figure 10 and 11 shows the performance of Type 1 office room with varying g values of the glazing under different climatic conditions. According to the simulation results, during the heating period, it is much better to select windows with high solar transmittance which allows more solar heat gain and reduces the annual heating load in all climate zones (Fig.10). During the heating period, south oriented office room located in Izmir with highest total solar transmittance value of the glazing (g=0.624), has the lowest energy consumption between all models due to the high levels of solar heat gain. While as expected, glazing type with lowest g value (g=0.212) has the highest heating demand for the north facing office room located in Hakkari. As a result, during the heating season, best performance has been obtained in Izmir by selecting windows with high g values, and Istanbul, Ankara and Hakkari follow it. Simulation results, in general, indicate that sufficient access to solar gains can decrease space heating demand significantly. Findings in this paper showed that changing the g values of the glazing from 0.212 to 0.624 may lead to a reduction in space heating demand between 6.32 to 33.53 kWh/m^2 annually in all regions.

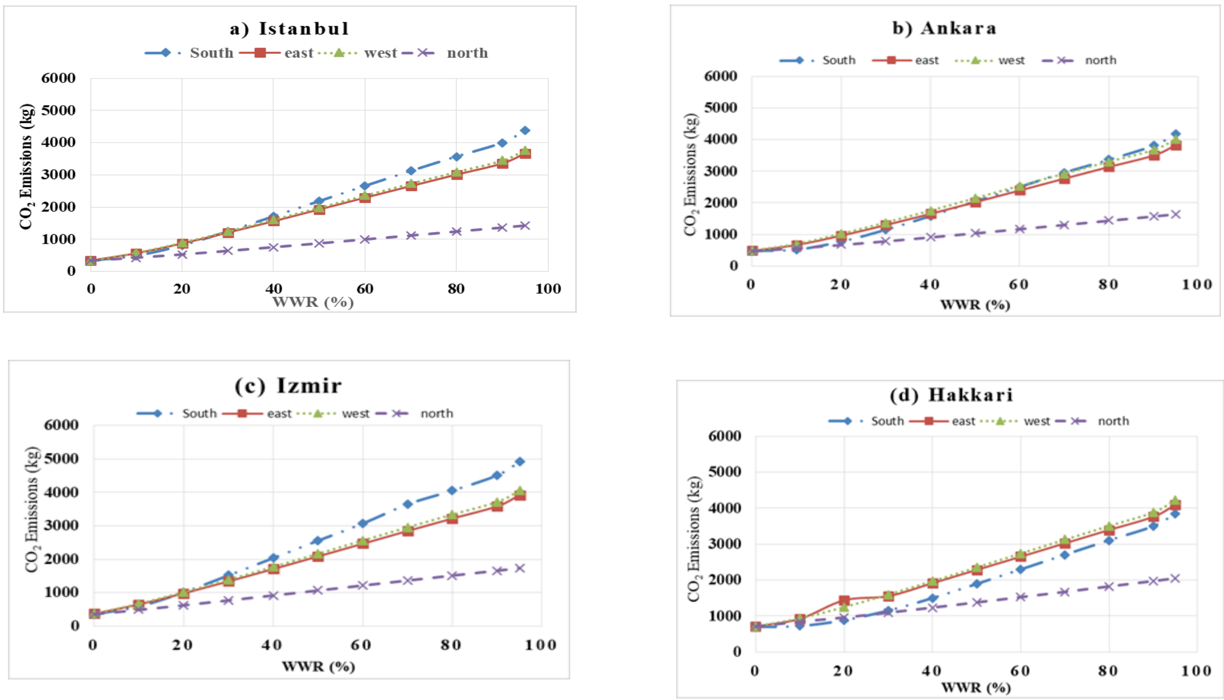

Figure 8. The effects of WWR on CO_2 emissions corresponding to annual heating and cooling energy use in Type 1 room: a)Istanbul b) Ankara c) Izmir d) Hakkari

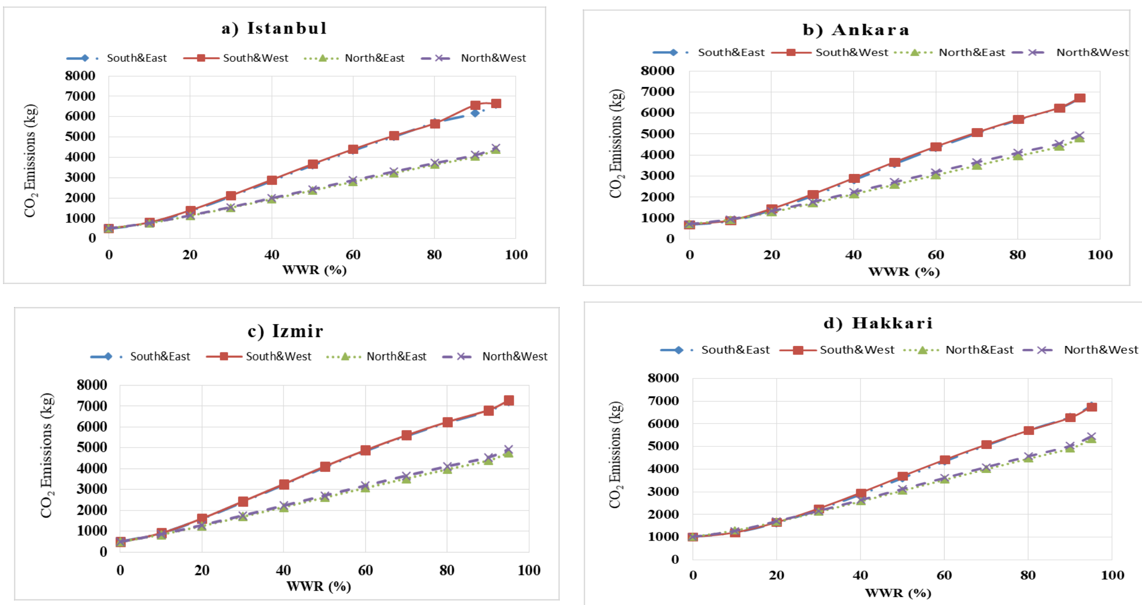

Fig.9. The effects of WWR on CO_2 emissions corresponding to annual heating and cooling energy use in Type 2 room**:** a)Istanbul b) Ankara c) Izmir d) Hakkari

Figure 11 shows the cooling season energy requirement of Type 1 office room with varying g values of the glazing. Conversely, results present that windows with higher solar transmittance value show a worse performance due to overheating during the cooling season. Cooling load increases significantly with higher g value regardless of the climate zone. Regarding only cooling energy demand, maximum energy is required for the south-oriented room located in Izmir, with the highest g value of the glazing, when compared to the other cases. Solar heat gain in an office room increases cooling load, and the north orientation allows relatively low solar heat gain and seem to be a much convenient direction concerning energy savings [21]. Consequently, the case of the north-oriented office room with the lowest solar transmittance value located in heating-dominated climate zone shows the best performance regarding energy efficiency. During the heating period, use of windows with high solar transmittance is useful, but during cooling period higher solar transmittance considerably worsens energy performance of the building [15]. Therefore, the influence of g value of the glazing on both heating and cooling period is considered to select the best alternative. With considering both annual heating and cooling loads, selecting glazing products with minimum solar transmittance value (g=0.212) is recommended for regions located in warmer climate zones (Izmir and Istanbul) and selecting windows with medium solar transmittance value (g=0.298) is recommended for regions located in colder climate zones (Hakkari and Ankara) for energy efficiency.

In Figure 12 and 13 annual energy load of Type 2 room with changing g values of the glazing is presented. Similar to previous findings, glazing types with high g-values allow for lower heating energy demand and higher cooling energy demand. Results show that south + east and south + west oriented rooms with the highest g value glazing products have the lowest energy demand during the heating season located in Izmir. Whereas, north + east and north + west oriented rooms with lowest g-value glazing products located in Hakkari province gave the worse energy performance during the heating season. As a result, in terms of heating energy saving, low g-value glazing products are not preferable in all regions, specifically in heating-dominated climate zone.

Fig. 13 shows the relationship between varying g-values of the glazing products and annual cooling load of Type 2 model. As it can be seen from the figure 13, lowering the solar transmittance value of the glazing products significantly decrease annual cooling energy requirement for all climate zones. Minimum cooling energy demand is observed in north + east facing room with lowest g-value glazing products, located in Ankara and it is followed by Hakkari, Istanbul and Izmir, respectively. Maximum energy requirement is observed in south + west facing room with highest g-value glazing products, located in Izmir and it is followed by Istanbul, Ankara and Hakkari respectively. When looking at total energy balance, solar transmittance value of the glazing products has a minimum impact on energy consumption in both north + east and north + west oriented rooms for all climate zones. Results show that increasing tendency of total energy consumption for south + east and south + west oriented rooms with higher solar transmittance values of the glazing products can be observed for all climate zones, but more significantly in regions located in cooling-dominated climate zone. As a result, it can be concluded that, varying g-value of glazing products does not have a significant impact on total energy consumption of the office rooms located in heating-dominated climates, whereas, it contributes a significant change in cooling-dominated climate.

3.3 Contribution of shading on annual heating and cooling loads

Shading factor (SF) of windows is commonly used for expressing the effects of external solar controls such as overhangs, louvers or external objects. External shading factor of external windows can be defined by TRNSYS users to investigate the detailed treatment of shortwave beam radiation shading by external shaders [10]. Shading factor of windows varies between the value of 0 (no shading) to 1 (completely shaded). Value of 0.5 external shading factor means that only half of the incident diffuse radiation and half of the incident beam radiation will fall on the glazing. External shading devices have been commonly implemented in places where solar radiation is important in influencing the cooling load of a building [31]. As a result, optimal design of shading devices would decrease annual cooling load significantly, therefore proper selection of the shading devices is a crucial decision concerning energy saving. Fig. 14 shows the energy performance of shading devices in Type 1 office room, regarding orientations and the climate data. Simulation results show that increasing the shading level of windows results in an increment in annual heating consumption while a decrease in annual cooling consumption for all cases. During the heating season, heavily shaded condition (SF=0.75) of north oriented rooms located in heating-dominated climate zone has the greatest amount of energy demand with 80 kWh/m^2 year. Whereas, no shading condition (SF=0) of south oriented room located in cooling dominated climate zone has the lowest heat energy requirement between all models. The energy behavior of east oriented model is very similar to west-oriented model in all climate zones. Fig. 15 shows the change in cooling energy demand with changing shading conditions. In all cases, changing the shading conditions from no shading to heavily shading (SF=0-0.75), decreases annual cooling energy consumption remarkably. As the window shading level increases, less energy would be transferred into the building from window via solar radiation [32]. As a result, increasing the shading factor of the models leads to a decrease of cooling energy consumption for all orientations and climatic conditions during the cooling season. Between all models, the best performance application case of shading devices is the case of the heavily shaded condition of north-oriented room located in Ankara and it is followed by Hakkari, Istanbul and Izmir.

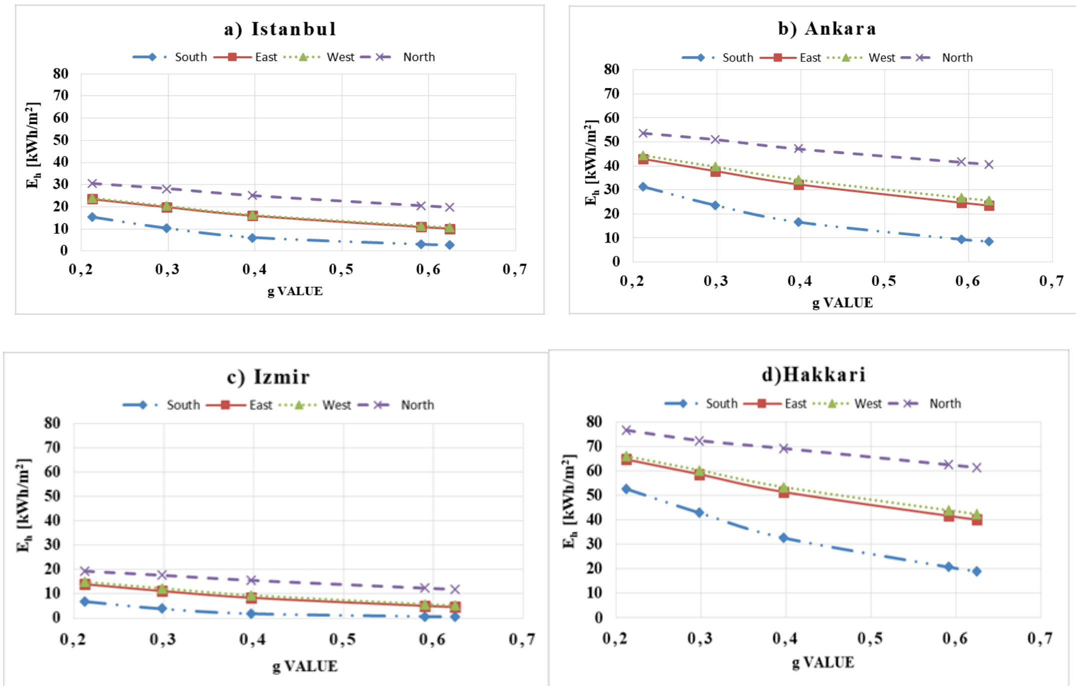

Figure 10. Annual heating load (E_h) of Type 1 room with changing g values of the glazing a) Istanbul b) Ankara c) Izmir d) Hakkari

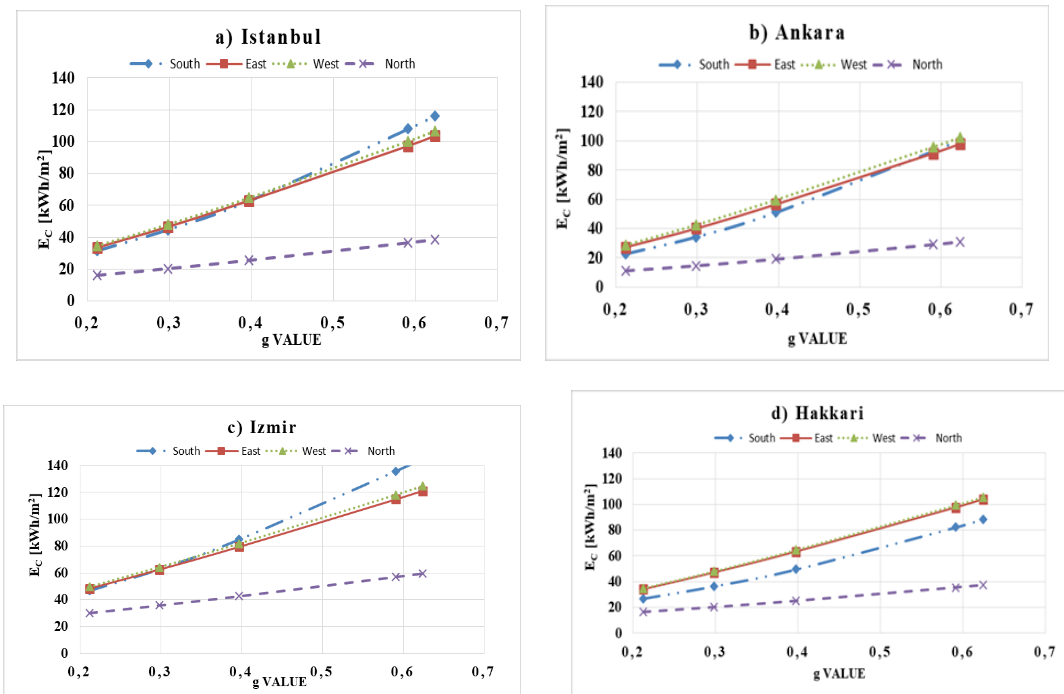

Figure 11. Annual cooling load (E_c) of Type 1 room with changing g values of the glazing a)Istanbul b) Ankara c) Izmir d) Hakkari

As expected, worst energy performance scenario during cooling season is obtained in the south oriented room with no shading device, located in Izmir with 135 kWh/m^2 With considering total annual energy balance, in regions located in colder climate zones like Hakkari and Ankara, it is much better not to apply any shading devices to north facing rooms, while it has no considerable impact on total energy balance. The presence of shading devices has greater energy saving potential in south-oriented office rooms located in cooling-dominated climate zone when compared to the other cases. Shading devices have a smaller impact on annual energy consumption for south oriented office rooms located in the heating-dominated climate zone, as energy saving caused by shading devices during summer season cannot be compensated by energy losses during wintertime.

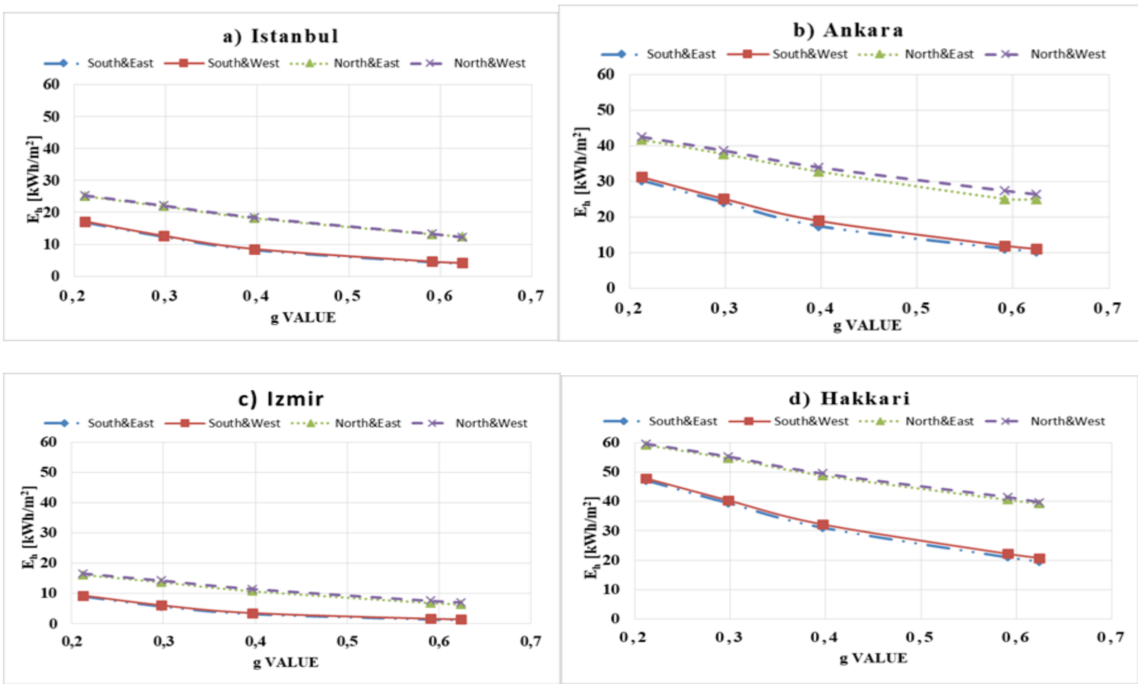

Figure 12. Annual heating load (E_h) of Type 2 room with changing g values of the glazing a)Istanbul b) Ankara c) Izmir d) Hakkari

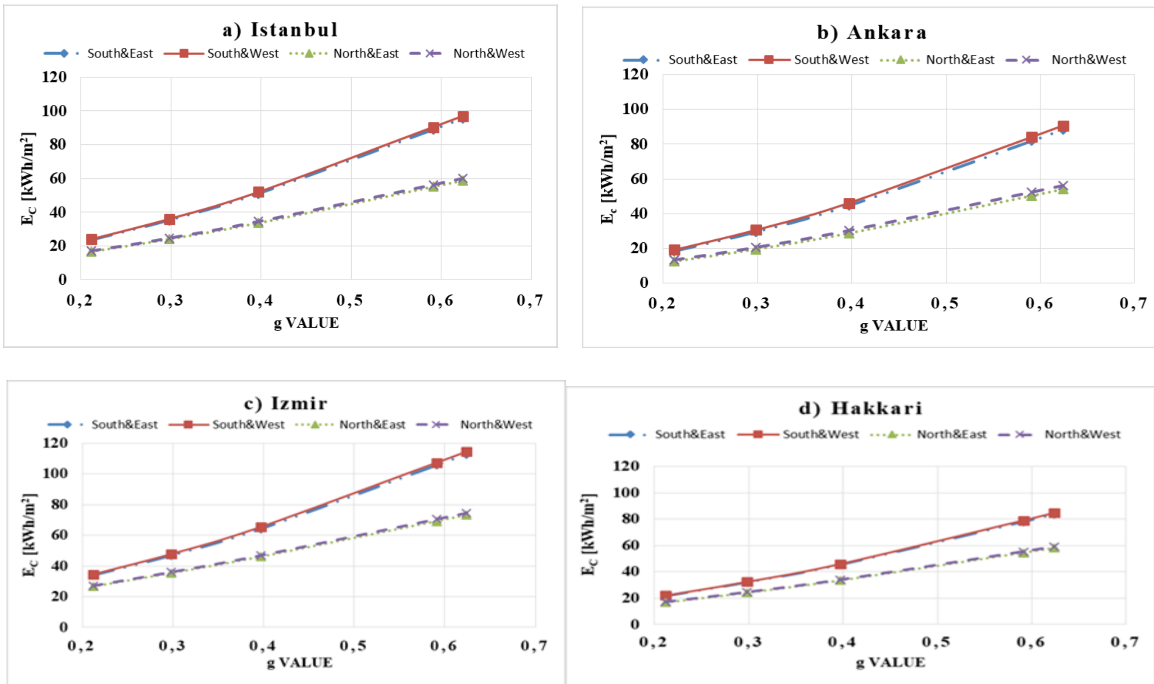

Figure 13. Annual cooling load (E_c) of Type 2 room with changing g values of the glazing a)Istanbul b) Ankara c) Izmir d)Hakkari

Therefore, it can be concluded that application solar control devices can be useful and its importance is higher specifically for office buildings located in the cooling-dominated zone. In general, the benefit obtained during the summer with utilization of shading devices is superior to the winter detriment for decreasing solar benefit in office buildings located in the cooling-dominated zone [23]. As a result, application of intense shading conditions (SF=0.50-0.75) should be imposed for Type 1 office units located in cooling dominated and temperate climate zones for south facing models. Whereas, light shading (SF=0.25) conditions are recommended for south-oriented office units located in heating-dominated climate zone. 50 % shading effect is recommended for east and west facing models located in cooling-dominated, heating-dominated and temperate climates in terms of energy saving.

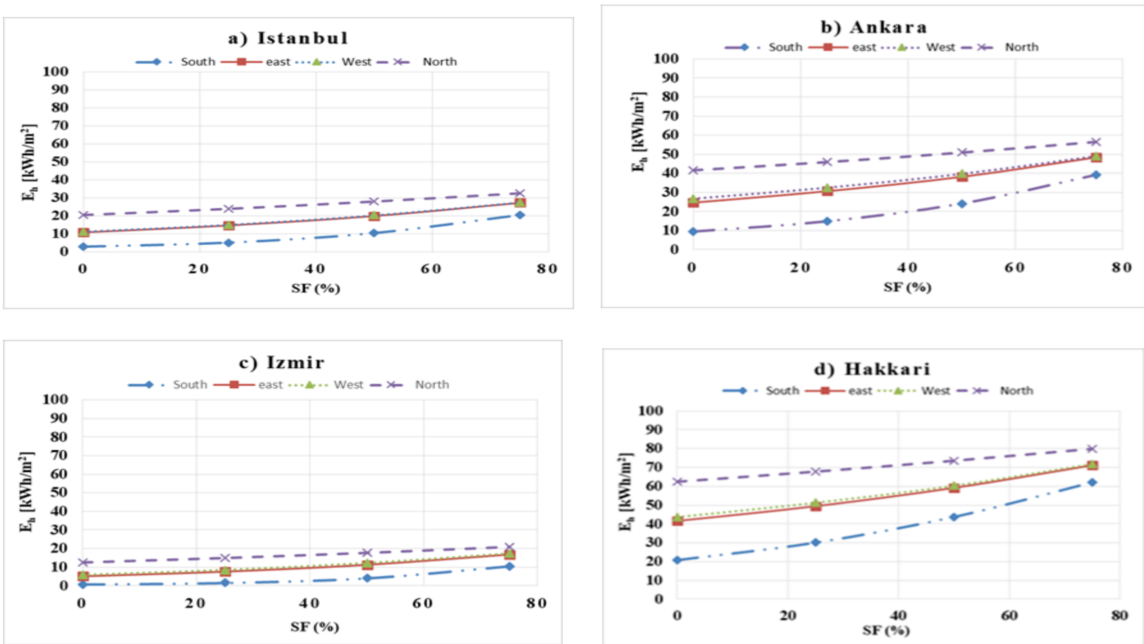

Figure 14. Annual heating (E_h) load [kWh/m^2] of Type 1 room with changing shading factor (SF)

a)Istanbul b) Ankara c) Izmir d) Hakkari

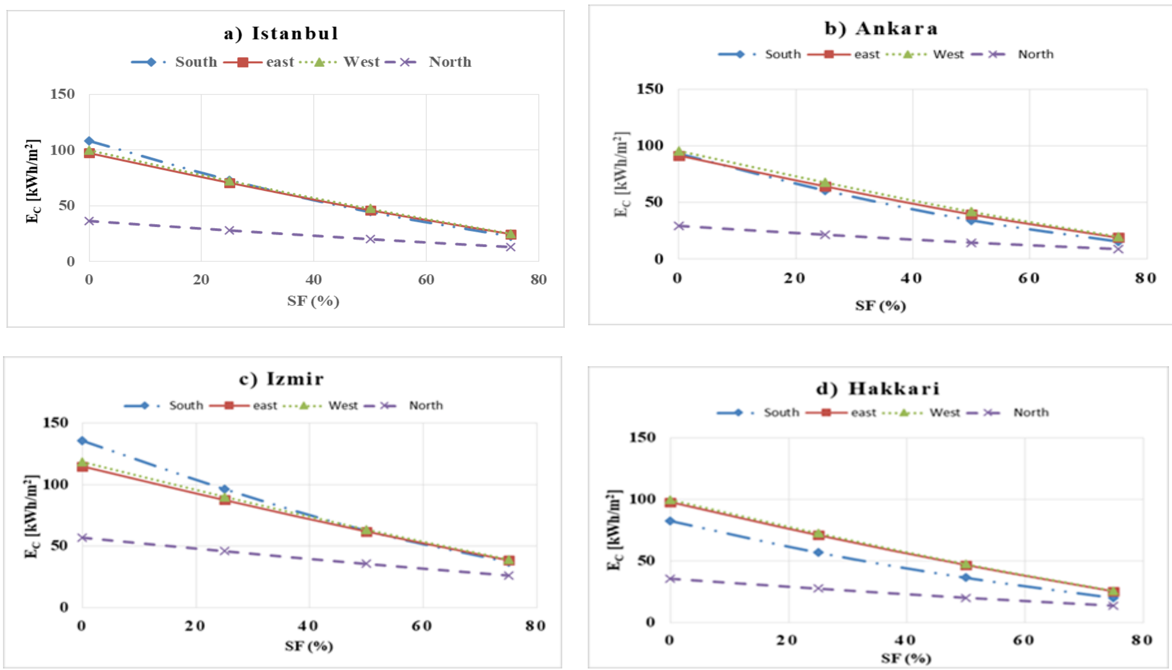

Figure 15. Annual cooling (Ec) load [kWh/m^2] of Type 1 room with changing shading factor (SF) a)Istanbul b) Ankara c) Izmir d) Hakkari

Since shading devices do not contribute to the thermal performance in the north orientation significantly in all regions, light shading condition (SF=0.25) and no shading condition (SF=0) is recommended for office units located in cooling-dominated & temperate and heating-dominated climates respectively. Fig.16 and 17 summarizes the impact of shading levels on annual energy consumption of Type 2 office room for different Turkish climates. According to the results, increasing values of shading factor of fenestration products results in higher energy consumption during the heating season (Fig.16) and lower energy consumption during the cooling season in all regions (Fig.17).

As it can be seen from the figures, north + west oriented office unit with intense shading condition (SF=0.75) located in Hakkari has the greatest heating energy demand with 64.67 kWh/m^2, whereas, south + east oriented office room with no-shading condition (SF=0) located in Izmir has the lowest annual heating energy load with 1.47

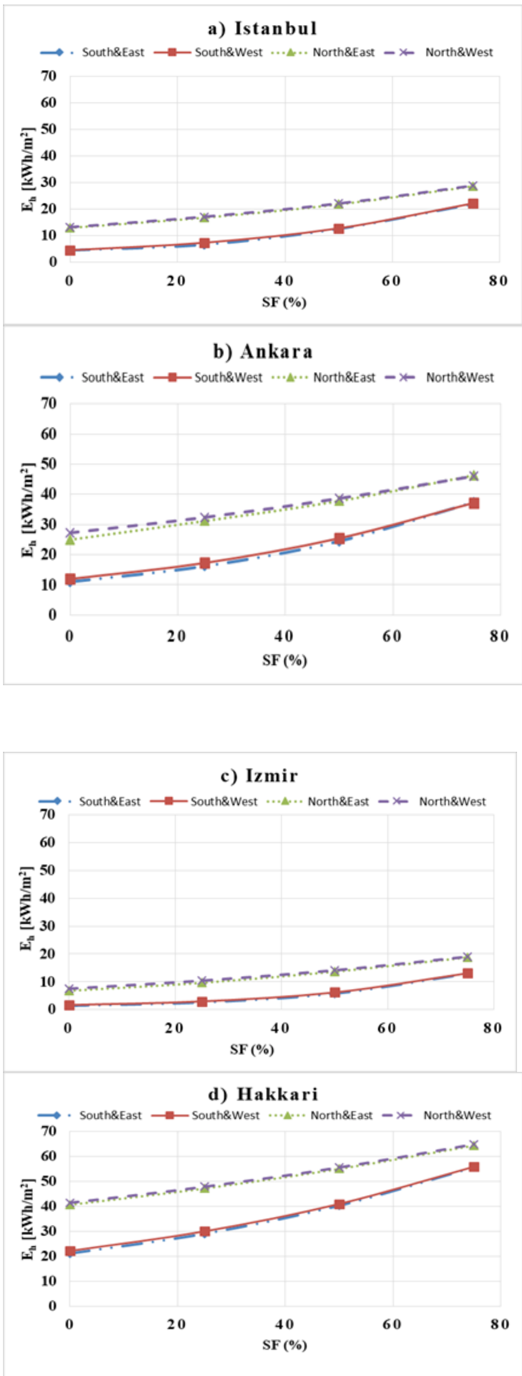

Figure 16. Annual heating (E_h) load [kWh/m^2] of Type 2 room with changing shading factor (SF) a)Istanbul b) Ankara c) Izmir d) Hakkari

energy demand during the cooling season with 107.3 kWh/m^2. North + east oriented office room with intense shading conditions (SF=0.75) located in Ankara has the lowest cooling energy demand between all cases with 7.97 kWh/m^2.

kWh/m^2. Conversely, the case with no-shading condition (south + west) located in Izmir gave the highest cooling

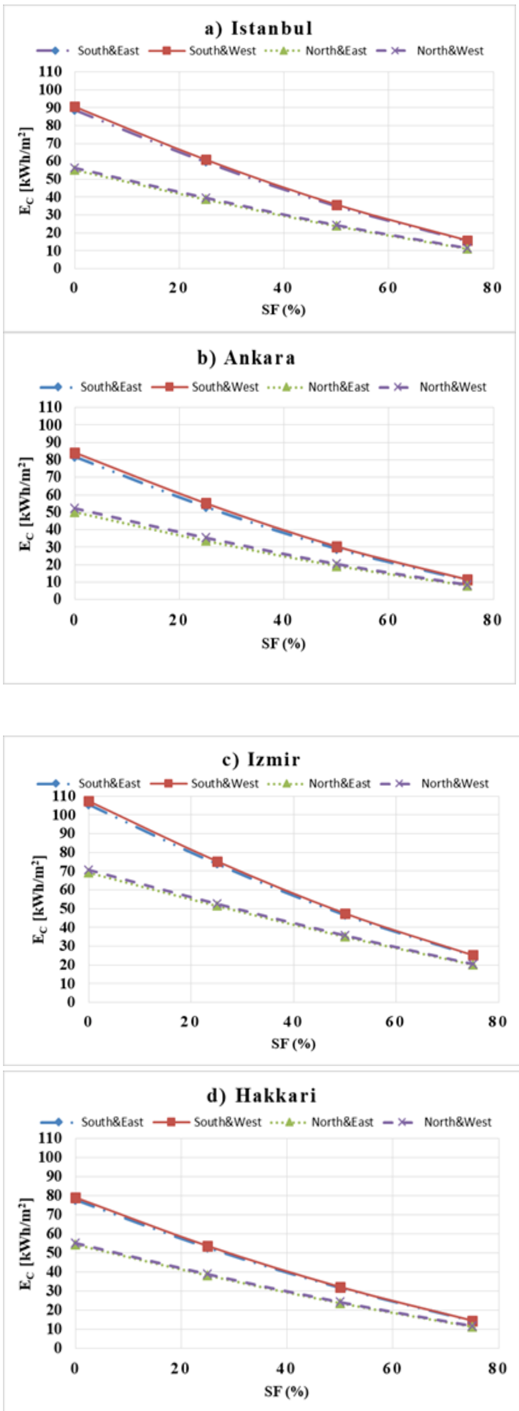

Figure 17. Annual cooling (E_c) load [kWh/m^2] of Type 2 room with changing shading factor (SF) a)Istanbul b) Ankara c) Izmir d) Hakkari

Looking at total energy balance, despite the fact that, application of shading devices on south + east and south + west oriented office units also decreases the total energy consumption in heating-dominated climates, when compared to the cases in cooling-dominated climates, it has a minimal impact. Using shading devices is not recommended for north + east and north + west faced office units located in heating-dominated climate zone where the benefit obtained during cooling season cannot compensate for the heat losses during heating season because of the inadequate solar heat gain. Whereas their application is highly advisable in south + east and south + west oriented office rooms located in cooling-dominated and temperate climates.

4. Conclusions

The energy efficiency of buildings is very crucial nowadays, and it highly depends on the early design. As a result, during the very early stage of a building, decisions of the designers, building owners, engineers and architects are very important. As expected, annual energy load of a building is significantly influenced by thermo-physical properties, geometrical characteristics and other features of the windows. The main aim of this article is to investigate the impact of window and façade characteristics on annual energy requirements of two very common office room models for different climate zones in order to inform building designers for better decisions. The relationship between various window parameters and how these factors influence annual energy load were studied for two reference office units which are the most common office models worldwide. In total 640 alternative scenarios regarding four climatic zones of Turkey were simulated with using well-known simulation code TRNSYS. The main findings of this study are summarized as follows:

(1) From all studied cases, the most influential parameter on annual energy consumption is the window-to-wall ratio. At all case study locations, north-facing office units have the greatest energy demand, and south-facing office units have the lowest energy demand during the heating season. For the west, east and south exposed type 1 office units, the optimal configuration has a WWR between 40% and 60% during the heating season. However, in the case of north facing office unit, increasing WWR does not have a positive impact on energy saving in all locations, therefore it is not recommended. For the case of Type 2 office room model during the heating season, increasing the WRR above 20% is not recommended for north + east and north + west exposed rooms located in heating-dominated climate zone. For the south + east and south + west models, the optimal configuration has a WWR between 30% and 50% in all regions.

(2) For all cases, with considering total energy balance, similar tendencies of increasing of CO_2 emissions with increasing window size can be observed in all locations but in different magnitudes. Therefore it is recommended to reduce the window size to decrease greenhouse gas emissions and achieve thermal comfort conditions for the occupants

(3) Solar transmittance value (g value) of the glass is an important parameter on energy demand, therefore it is very important to pay attention when selecting a window.

Selecting window with high g values provide more solar benefit which reduces an annual heating load in all climate zones. In contrast, with the use of high g value glazing products, energy demand increases in all climate zones during the cooling season. Findings of this paper showed that varying g value of the glazing products do not have a significant impact on total annual energy consumption of north, north-east, and north-west oriented office room models located in heating-dominated climates but it may contribute significant energy savings in cooling-dominated climates. An optimal value of solar transmittance is found as 0.212 for cooling-dominated and temperate climates, whereas medium solar transmittance value of 0.298 is recommended for colder regions.

(4) Solar protection via shading devices can be useful in terms of lowering annual energy demand. Different shading conditions are studied in this paper with varying the external shading factor of the window. Findings of the study showed that increasing the shading level of windows results an increment in annual heating consumption while a decrease in annual cooling consumption for all cases. Based on the results of this study, with considering total energy balance, no shading (SF=0) and light shading (SF=0.25) conditions are recommended for north, north + east and north + west facing office room models in heating-dominated and cooling-dominated & temperate climates, respectively. Whereas, intense shading conditions (SF=0.50-0.75) and light shading conditions (SF=0.25) are recommended for south, south-east and south-west oriented office rooms located in cooling-dominated & temperate and heating-dominated climates, respectively.

Regarding the findings summarized above, a building designer should take into account climatic conditions, orientations, shading conditions, thermal properties of the glazing and window-wall configuration when selecting windows.

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