DOI: 10.38027/N62020ICCAUA316363

Evaluation of the Impact of the Transparent Component on the Energy Loads and Thermal Comfort Conditions in Different Climatic Regions

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Abstract
Due to rapid depletion of energy resources and environmental problems caused by the use of energy resources, controlling energy consumption is becoming increasingly important. As cooling and heating demands of buildings constitute a majority of the energy consumed, energy efficient buildings in which comfort conditions are achieved have become important. Decisions about the opaque and transparent components of a building in the design stage and orientation of these components in different climatic regions have a significant effect on the thermal comfort conditions and energy consumption rates in the building. Therefore, this study intends to review and evaluate the impact of design decisions on thermal comfort conditions and energy consumption in buildings in different climates. In this study, a zone with 5/5 dimensions was designed in Istanbul (temperate-humid), Diyarbakır (hot-dry) and Erzurum (cold) in Turkey to conduct thermal comfort and energy analyses. Overall annual energy loads, solar radiation gains and operative temperature changes as a result of using two different transparency ratios (30% and 50%) and different orientation and location of windows in the zones will be evaluated in this study. Energy efficient design options with thermal comfort will be determined based on comparative analyses.
Keywords: Energy Efficient Building; Energy loads; Operative temperature; Transparency Ratio; Orientation; Window location .

1. Introduction

Changes and advances in technology in the world following the industrial revolution enhanced the role energy plays in people's lives. Increasing population and changes in personal needs have led to an increase in demand for energy resources. The increase in the use of fossil fuels to meet increasing energy needs resulted in the rapid depletion of natural resources and thus in an increase in environmental problems. According to the scenarios developed, fossil fuels will remain to be the dominant resource until 2040 although the consumption may partially decrease. (ETKB,2017).Energy efficient approach to use available fossil fuels efficiently and reduce their negative impact on the environment has become a priority in many countries.

When we look at the distribution of the total energy consumption according to industries, we see that the energy consumed in buildings, similar to the world, constitutes a big part of the total energy consumption in our country. The percentage of the energy consumed in buildings has reached to 40% of the total energy consumed and it seems likely that it will continue to increase with the increasing number of buildings. (Yıldız, Özbalta, Arsan, 2011) In buildings, majority of the energy is consumed by heating and cooling systems to achieve thermal comfort conditions. Therefore reduction of energy use to achieve thermal comfort conditions with the decisions taken during early design stage is among the focus priority areas. Energy efficient designs with which energy consumption is minimum and thermal comfort conditions are met are achieved by reducing the use of active systems which increase energy consumption and improving the performance of passive systems which lead to less demand for heating and cooling energy. (Manioğlu 2011)

Built environment variables which affect energy efficient designs include the location of the building, its position compared to other buildings, orientation, building form and optical and thermophysical characteristics of the building envelope**.** (Gümüş, 2011) Internal environmental conditions which change with different climate conditions are affected by these design parameters. Orientation of the building, window location and transparency ratio selected according to climate conditions are among the most effective factors considered in the energy efficient design stage. With correct decisions about built environment which can be taken during the design stage, interior thermal comfort conditions can be achieved with less energy load and building energy consumption can be reduced. This study investigates energy loads, solar radiation gains and operative temperature changes occurred depending on the orientation, transparency ratio and window location in a single zone building in different climatic regions. Alternatives for orientation, transparency ratio and window location in the zone depending on different climate characteristics were selected to determine the effects of the decisions taken in the design stage on the building's energy performance.

2. Study Method

This study intended to emphasize the impact of decisions taken during early design stages to achieve energy efficiency in buildings and to minimise energy consumption. Important passive climatisation parameters which significantly affect energy consumptions such as transparency ratio, window location and building orientation cannot be changed after the design stage. Therefore such decisions need to be taken during early design stage depending on the conditions of the selected climatic region. This approach can significantly reduce heating and cooling loads for energy efficient design. Calculations of energy loads and thermal comfort conditions in zones developed with alternatives of transparency ratios, orientation of the building and window location as selected for the study were done with the Design Builder simulation program which runs with Energy Plus Simulation motor. Design Builder is a dynamic thermal building energy simulation program developed by the U.S. Department of Energy to review and evaluate energy performance of a building and built systems of the building.

2.1 Determining Assumptions for Climate and Building

Three cities; Istanbul (temperate-humid), Diyarbakır (hot-dry) and Erzurum (cold) that represent different climatic regions of Turkey were selected for the study. The dimensions of the single unit building evaluated in the study are 5m x 5m and with 3 m height and flat roof on a level land (Figure 1). The building used in this study was assumed not to be subject to any shadowing caused by other buildings.

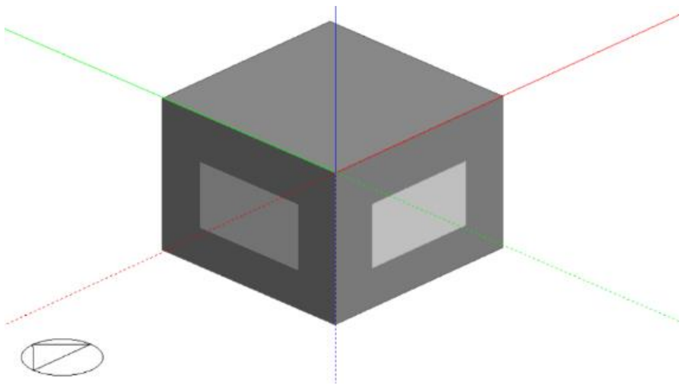


Figure 1: The model of the single zone building

All evaluations are made by using the same single zone building;

- in three climatic regions,
- with 30% and 50% transparency ratios,
- with N-S and E-W orientation when windows are located on opposite walls and
- with S-W, S-E, N-E and N-W orientation when windows are located on adjacent walls.

12 different building forms were created for each climatic region with these variables. The model alternatives created for the study are shown in Table 1.

		Windows on Opposite Wall		Windows on Adjacent Walls			
		N-S	E-W	S-W	S-E	N-E	N-W
Transparency Rate	30%	N-S(30)	E-W(30)	S-W(30)	S-E(30)	N-E(30)	N-W(30)
	50%	N-S(50)	E-W(50)	S-W(50)	S-E(50)	N-E(50)	N-W(50)

Table 1. Model alternatives created using different transparency ratios, orientations and window locations for each climatic region

The heat transfer coefficient of the double glazed windows with wooden framework used in calculations in the single zone building is U: 1.712 W/m2K and it meets the limit values prescribed in the standard TS-825 "Thermal insulation requirements for buildings". Istanbul and Diyarbakır are in the 2nd and Erzurum is in the 5th degree day region according to TS-825. (TS 825, 2013). Building envelope details were developed to achieve maximum total heat transfer coefficient values recommended in the standard for opaque components in the 2nd and 5th degree day regions. Building envelope details created according to this limit values in the models and thermophysical properties of materials are shown in Table 2 and 3. Same materials were used in these envelope alternatives and only insulation thickness was changed to meet the required total heat transfer coefficient value in each region. The material catalogue in the Design Builder simulation program was used to select materials.

Table 2: Layering details of the opaque component of the single zone building (Istanbul-Diyarbakır)

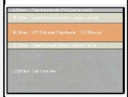
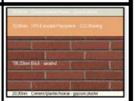
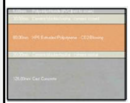
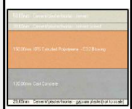
	Layers	Thickness (m)	Conductivity (W/m-K)	Heat Transfer Coefficient U-Value (W/m2-K)	TS 825 Heat Transfer Coefficient U-Value (W/m2.K)	Section
External Wall	Gypsum Plaster	0,02	0,51	0,566	0,57	
	Brick	0,19	0,72			
	XPS	0,03	0,034			
	Cement Plaster	0,03	0,72			
Floor	PVC	0,005	0,17	0,536	0,57	
	Cement Screed	0,03	1,4			
	XPS	0,05	0,034			
	Mortar	0,02	0,72			
	Concrete	0,12	1,13			
Roof	Gypsum Plaster	0,02	0,51	0,366	0,38	
	Concrete	0,12	1,13			
	XPS	0,08	0,034			
	Cement Screed	0,03	1,4			
	Mortar	0,05	0,72			
Window	Clear Glass	0,03	0,9	1,712	1,8	
	Argon	0,13	0,04			
	Clear Glass	0,03	0,9			

Table 3: Layering details of the opaque component of the single zone building (Erzurum)

	Layers	Thickness (m)	Conductivity (W/m-K)	Heat Transfer Coefficient U-Value (W/m2-K)	TS 825 Heat Transfer Coefficient U-Value (W/m2.K)	Section
External Wall	Gypsum Plaster	0,02	0,51	0,34	0,36	
	Brick	0,19	0,72			
	XPS	0,07	0,034			
	Cement Plaster	0,03	0,72			
Floor	PVC	0,005	0,17	0,36	0,36	
	Cement Screed	0,03	1,4			
	XPS	0,08	0,034			
	Mortar	0,02	0,72			
	Concrete	0,12	1,13			
Roof	Gypsum Plaster	0,02	0,51	0,2	0,21	
	Concrete	0,12	1,13			
	XPS	0,15	0,034			
	Cement Screed	0,03	1,4			
	Mortar	0,05	0,72			
Window	Clear Glass	0,03	0,9	1,712	1,8	
	Argon	0,13	0,04			
	Clear Glass	0,03	0,9			

2.2 Determining Assumptions for Calculations

Heating, cooling and overall loads, solar radiation gains and operative temperatures in zones in the building models with different transparency ratios, orientations and window locations were found with the calculations made. Operative temperature is a temperature type which represents both indoor air temperature and mean radiant temperature and which is used to measure occupant's heat loss in a simple way when calculating indoor thermal comfort conditions. (Atmaca, Abdullah at al., 2009, 2013) A system running on natural gas was chosen as the heating system and an electrical system was chosen as the cooling system in the calculations. Indoor air temperature was assumed to be 21°C in the heating period and 26°C in the cooling period. When the indoor temperature drops below 19°C heating systems and when the indoor temperature rises above 28°C cooling systems were assumed to be turned on. Climate data in epw. (energy plus weather) format of Istanbul, Diyarbakır and Erzurum was used in the Design Builder simulation program to calculate energy loads. Design Builder is a user friendly, visual interface program which uses Energy Plus program with high calculation capacity which uses algorithms such as transfer function, finite difference method and finite elements and with which heating, cooling, lighting, ventilation and other energy flow system can be modelled. (Design Builder, 2019) Annual heating, cooling and overall energy consumption in the zones based on the calculations are shown in Figures 2, 3, 4.

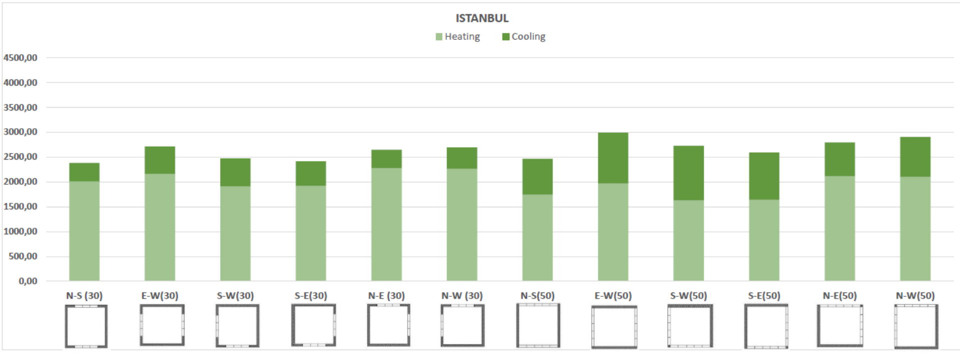


Figure 2: Annual heating, cooling and overall energy consumption for Istanbul

According to the results included in Figure 2, evaluations about the energy loads that change with the orientation and transparency ratios in Istanbul are shown below.

- Annual overall energy consumptions in zones with 30% and 50% transparency ratio are, in ascending order: windows located in the direction of N-S, S-E, S-W, N-E, N-W, E-W.
- With 30% transparency ratio, the lowest overall energy load was the N-S(30) alternative with 2381.11 kWh and the highest overall energy load was the E-W(30) alternative with 2715.02 kWh.
- With 50% transparency ratio, the lowest overall energy load was the N-S(50) alternative with 2467.83 kWh and the highest overall energy load was the E-W(50) alternative with 2992.68 kWh.
- The alternatives starting with the one with the lowest until the one with the highest energy consumption for Istanbul are listed in ascending order as following: N-S(30), S-E(30), N-S(50), S-W(30), S-E(50), N-E(30), N-W(30), E-W(30), S-W(50) N-E(50), N-W(50), E-W(50).
- In the alternatives where overall energy consumption changes depending on orientation, transparency ratio and window location, overall consumption amounts increased by 1.4%, 3.7%, 3.9%, 11.09%, 13.3%, 14.02.%, 14.6%, 17.33%, 22.03%, 25.7% compared to the condition with the lowest energy consumption.
- When annual overall energy consumption ratios were compared, N-S(50), S-W(30)and E-W(30), S-W(50) alternatives for Istanbul have very similar energy consumption ratios thus can be used as alternatives for each other.

  Among the alternatives developed for Istanbul;
- Heating energy consumption was the lowest in the S-W(50) alternative and the highest in the N-E(30) alternative. For each alternative evaluated, reducing transparency ratio from 50% to 30% increased heating energy consumption.
- Cooling energy consumption was the lowest in the N-E(30) alternative and the highest in the S-W(50) alternative. For all the alternatives evaluated, reducing transparency ratio from 50% to 30% decreased cooling energy consumption.

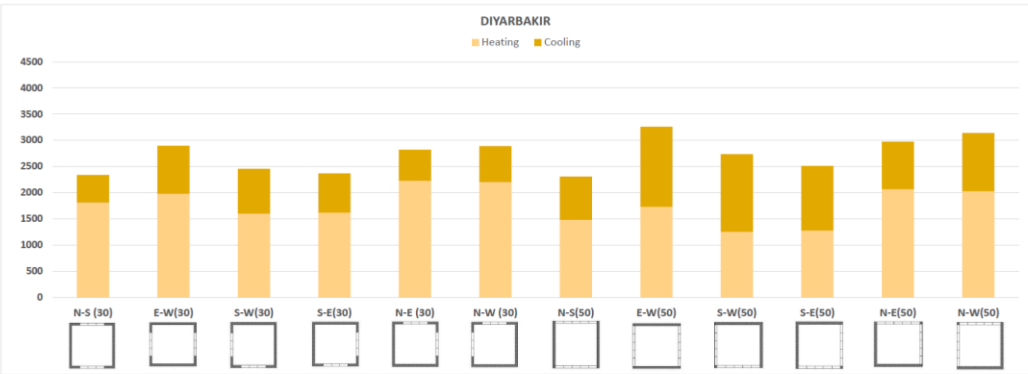


Figure 3: Annual heating, cooling and overall energy consumption for Diyarbakır

According to the results included in Figure 3, evaluations about the energy loads that change with the orientation and transparency ratios in Diyarbakır are shown below.

- Annual overall energy consumptions in zones with 30% and 50% transparency ratio are, in ascending order: windows located in the direction of N-S, S-E, S-W, N-E, N-W, E-W.
- With 30% transparency ratio, the lowest overall energy load was the N-S(30) alternative with 2340.94 kWh and the highest overall energy load was the E-W(30) alternative with 2898.35 kWh.
- With 50% transparency ratio, the lowest overall energy load was the N-S(50) alternative with 2310.23 kWh and the highest overall energy load was the E-W(50) alternative with 3260.85 kWh.
- The alternatives starting with the one with the lowest until the one with the highest energy consumption in Diyarbakır are listed in ascending order as following: N-S(50), N-S(30), S-E(30), S-W(30), S-E(50), S-W(50), N-E(30), N-W(30), E-W(30), N-E(50), N-W(50), E-W(50).
- In the alternatives where overall energy consumption changes depending on orientation, transparency ratio and window location, overall consumption amounts increased by 1.3%, 2.6%, 6.3%, 8.7%, 18.5%, 22.14.%, 25.22%, 25.45%, 28.85%, 36.03%, 41.15% compared to the condition with the lowest energy consumption.
- When annual overall energy consumption ratios were compared, N-W(30) and E-W(30) alternatives for Diyarbakır have very similar energy consumption ratios thus can be used as alternatives for each other.
  Among the alternatives developed for Diyarbakır ;
- Heating energy consumption was the lowest in the S-W(50) alternative and the highest in the N-E(30) alternative. For each alternative evaluated, reducing transparency ratio from 50% to 30% increased heating energy consumption.
- Cooling energy consumption was the lowest in the N-S(30) alternative and the highest in the E-W(50) alternative. For all the alternatives evaluated, reducing transparency ratio from 50% to 30% decreased cooling energy consumption.

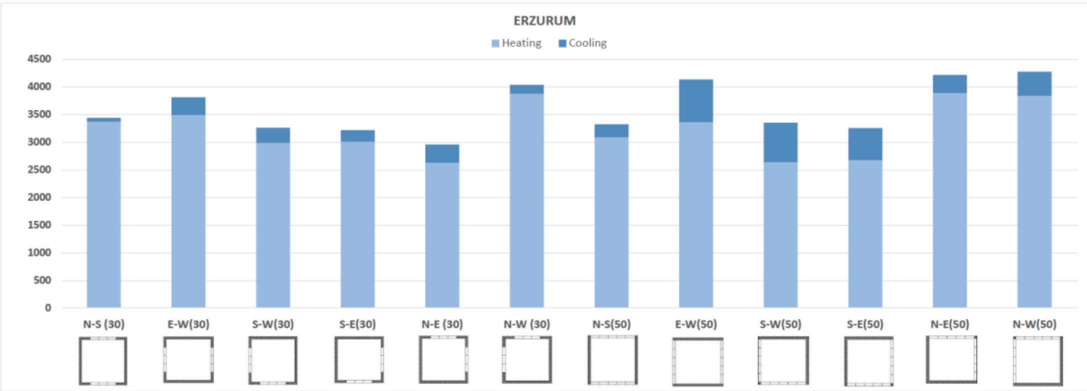


Figure 4: Annual heating, cooling and overall energy consumption for Erzurum

According to the results included in Figure 4, evaluations about the energy loads that change with the orientation and transparency ratios in Erzurum are shown below.

- Annual overall energy consumptions in zones with 30% and 50% transparency ratio are, in ascending order: windows located in the direction of N-E, S-E, S-W, N-S, E-W, N-W for alternatives with 30% transparency ratio; and of S-E, N-S, S-W, E-W, N-E, N-W for alternatives with 50% transparency ratio.
- With 30% transparency ratio, the lowest overall energy load was the N-E(30) alternative with 2959.14 kWh and the highest overall energy load was the N-W(30) alternative with 4040.41 kWh.
- With 50% transparency ratio, the lowest overall energy load was the S-E(50) alternative with 3257.73 kWh and the highest overall energy load was the N-W(50) alternative with 4278.35 kWh.
- The alternatives starting with the one with the lowest until the one with the highest energy consumption in Erzurum are listed in ascending order as following: N-E(30), S-E(30), S-E(50), S-W(30), N-S(50), S-W(50), N-S(30), E-W(30), N-W(30), E-W(50), N-E(50), N-W(50).
- In the alternatives where overall energy consumption changes depending on orientation, transparency ratio and window location, overall consumption amounts increased by 8.8%, 10.10%, 10.20%, 12.4%, %13,4 16.3%, 28.95%, 36.55%, 39.84%, 42.6%, 44.58%, compared to the condition with the lowest energy consumption.
- When annual overall energy consumption ratios were compared, S-E(50) and S-W(30) alternatives for Erzurum have very similar energy consumption ratios thus can be used as alternatives for each other.

Among the alternatives developed for Erzurum;

- Heating energy consumption was the lowest in the N-E(30) alternative and the highest in the N-E(50) alternative. Except the N-E window location, reducing transparency ratio from 50% to 30% increased heating energy consumption in all alternatives.
- Cooling energy consumption was the lowest in the N-S(30) alternative and the highest in the E-W(50) alternative. For all of the alternatives evaluated, reducing transparency ratio from 50% to 30% decreased cooling energy consumption.

When we look at all of the calculations;

- With the design decisions about window location, building orientation and transparency ratio in the single zone building created in three climatic regions, it was seen that the amount of energy annually consumed can change in the range of 1.4% - 25.7% for Istanbul, 1.3% - 41.15% for Diyarbakır and 8.88% - 44.58% for Erzurum.
- Overall energy load increased with the increasing transparency ratio in the zone in all alternatives in three climatic regions except for the N-S alternative in Erzurum and Diyarbakır.
- When heating loads were evaluated, as the transparency ratio increased in all alternatives in three climatic regions,except the N-E window location in Erzurum, overall heating load decreased.
- When cooling loads were evaluated, as the transparency ratio increased in all alternatives in three climatic regions, overall cooling load increased.

Operative temperature and solar radiation values of alternatives on January 21st which represent the coldest day and July 21st which represents the hottest day of the year were calculated separately to evaluate the thermal comfort conditions of the selected zone. Operative temperature values and total solar radiation gain values through windows of the buildings according to the calculations are shown in graphs in Figures 5, 6, 7.

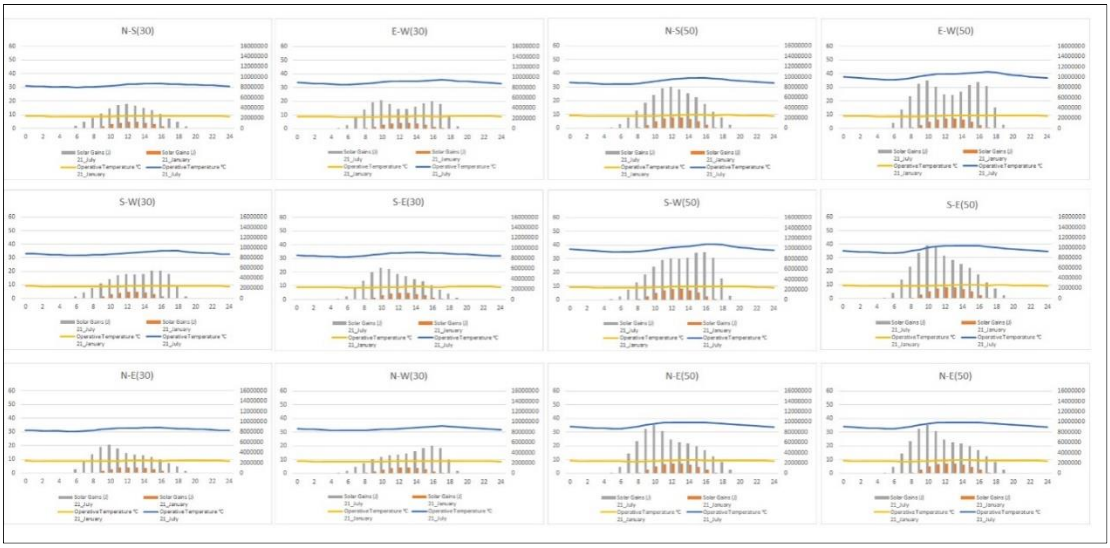


Figure 5: Solar radiation gain and operative temperature change on January 21 and July 21 in Istanbul.

- Orientation, window location and transparency ratios have more impact on the operative temperature in the heating period than the cooling period in Istanbul.
- On January 21, operative temperatures were higher and on July 21 operative temperatures were lower than the comfort temperature defined in the study.
- As the alternative with the lowest operative temperature is N-S(30) alternative on July 21, if this alternative is used, lower energy will be needed to achieve thermal comfort conditions.
- As transparency ratio increases, operative temperature increases on July 21.

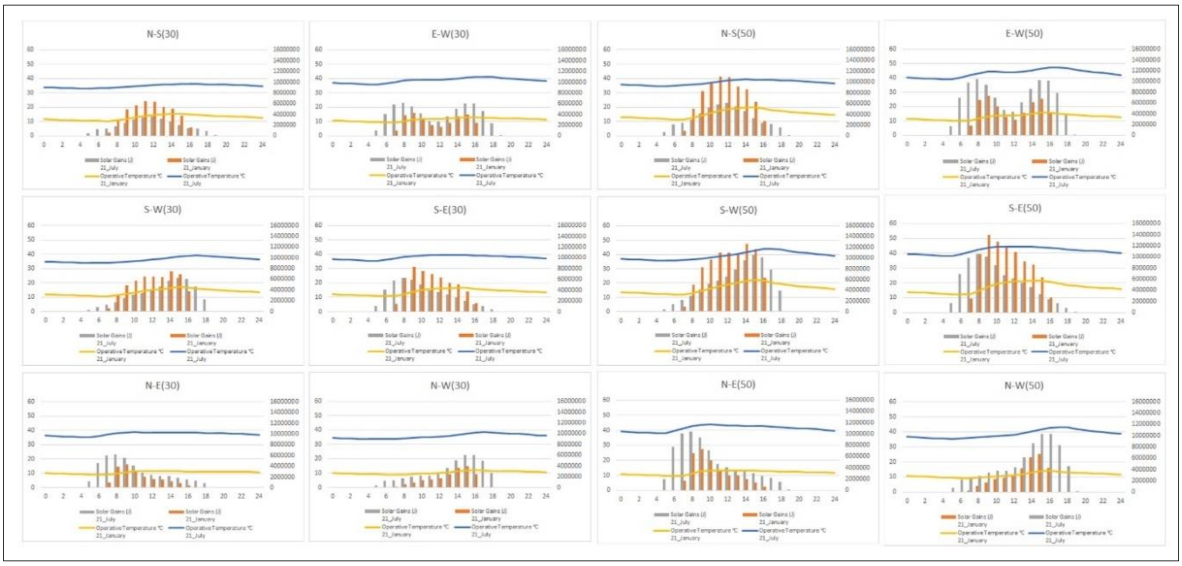


Figure 6: Solar radiation gain and operative temperature change on January 21 and July 21 in Diyarbakır.

- Orientation, window location and transparency ratios have an impact on the operative temperature both in the heating period and cooling period in Diyarbakır.
- Except for the N-S(50), S-W(50) and S-E(50) alternatives, on January 21, operative temperatures were lower and on July 21 operative temperatures were higher than the comfort temperature defined in the study.
- Orientation plays a bigger role than transparency in alternatives in which operative temperature increased on January 21 and July 21.

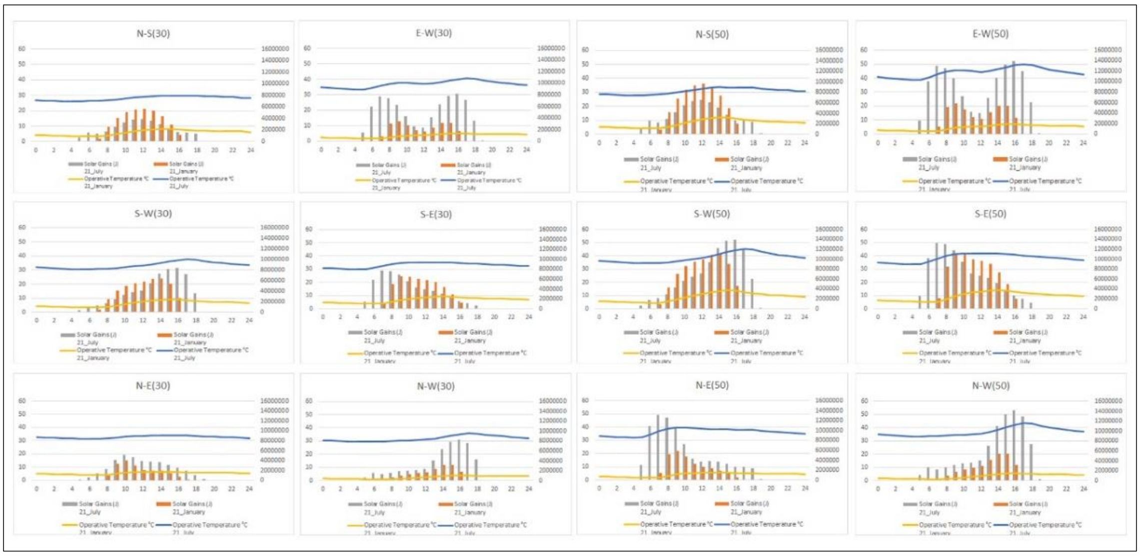


Figure 7: Solar radiation gain and operative temperature change on January 21 and July 21 in Erzurum.

- Orientation, window location and transparency ratios have an impact on the operative temperature both in the heating period and cooling period in Erzurum.
- On January 21, operative temperatures were higher and on July 21 operative temperatures were lower than the comfort temperature defined in the study.
- As the alternative with the lowest operative temperature is N-S(30) alternative on July 21, if this alternative is used, lower energy will be needed to achieve thermal comfort conditions.
- As the alternatives with the highest operative temperature are N-S(50), S-W(50) and SS-E(50) alternatives on January 21, if these alternatives are used, lower energy will be needed to achieve thermal comfort conditions
- Orientation plays a bigger role than transparency in alternatives in which operative temperature increased on January 21 and July 21.

3. Conclusions

Today, rapid depletion of energy resources and the increasing percentage of the energy consumed in buildings in the energy consumption of all industries lead to several problems. This study demonstrates the relationship between energy consumption and thermal comfort conditions based on the decisions taken during early design stages in different climatic regions and reviews the impact of such design decisions on the energy consumption. Based on the comparison and evaluation of the outcomes of the alternatives designed in the study, energy consumption ratios changed with the changes in outdoor climate data. Alternatives created by using different orientations, transparency ratios and window locations in the zones developed according to the requirements of the regulation using the Design Builder program were evaluated in different climatic regions. The study results are summarized below.

- The priority effect of the variables, i.e. transparency ratio, orientation and window location on heating, cooling and overall energy loads and operative temperature of buildings may vary in each climatic region.
- When 30% and 50% transparency ratios were used with different orientations and different window locations, the alternatives when listed for overall annual energy consumption from the lowest to the highest -in ascending order were similar in Istanbul and Diyarbakır but different in Erzurum.
- Very similar changes in loads ranging between 0.1% - 0.5% are observed in alternatives with different orientations, transparency ratios and window locations in all climatic regions. Thus it will be possible to achieve flexibility in design with alternative choices.
- According to the simulation results, heating loads constitute 89.7%, 74.6%and 65.1% of the annual overall heating and cooling loads in Erzurum, Istanbul and Diyarbakır respectively. Therefore decisions taken during the design stage can be more effective taking into consideration local climate conditions.
- According to the simulation results, cooling loads constitute 10.3%, 25.4% and 34.9 % of the annual overall heating and cooling loads in Erzurum, Istanbul and Diyarbakır respectively. Therefore decisions taken during the design stage can be more effective taking into consideration local climate conditions.
- When the zones have the same orientation, transparency ratio and window location, the cities listed for heating energy consumption from the lowest to the highest are Diyarbakır, Istanbul, Erzurum and the cities listed for cooling energy consumption from the lowest to the highest are Erzurum, Istanbul, Diyarbakır. The highest values for overall energy consumption were always in Erzurum however the cities with the second or third highest overall energy consumption changed between the other two cities, Istanbul and Diyarbakır.
- Although Istanbul and Diyarbakır are in the 2. Degree day regions according to the standard TS-825 'Thermal insulation requirements for buildings', different heating, cooling and overall energy loads were observed when energy loads were compared.
- When operative temperatures were evaluated, some alternatives had lower thermal comfort temperature than the defined temperature on January 21, and higher thermal comfort temperature than the defined temperature on July 21. In this case, it was observed that additional energy expenditure for heating and cooling systems can be reduced by selecting the alternatives in which conditions are closest to the desired comfort temperature value.

It is possible to identify the most efficient building form alternative, orientation, transparency ratio and window location which provide optimum comfort conditions using the parametric evaluation method discussed in this study. In future studies, designs that provide optimum comfort conditions will be possible by also analysing air movements inside buildings using the variables evaluated with computational fluid dynamic methods.

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