Determination of the Effect of Different Window Parameters Windows on Energy Consumption in Buildings by Design of Experiment

Res. Assist. Dr. Ahunur AŞIKOĞLU
ahunur.asikoglu@deu.edu.tr
Department of Architecture, Faculty of Architecture, Dokuz Eylül University, İzmir, Turkey
ORCID ID: 0000-0002-7227-1788

ABSTRACT
The increasing dependence on energy around the world necessitates the effective use of energy in every field for a sustainable world. Especially in the last 20 years, solutions for the energy efficiency have been developed in many sectors. In the field of architecture, laws and regulations have been developed, as the building sector has a great potential for energy consumption in both manufacturing and use phases. This study was conducted by analyzing the case study in TS 825 within the framework of TS 825 rules that must be followed in line with the "Regulation on Energy Performance in Buildings" published in Turkey. According to regulation, building elements should be within certain limit thermal conductivity values according to the climate zones. Case study's wall, floor and roof elements were modeled according to U-values required in the 1st degree climate zone. In order to investigate the effect of different parameters of windows on total energy consumption, scenario combinations were created using the statistical design of experiments method. Finally, it was found that the ratio of windows to facades and thermal conductivity values affect the total energy consumption at the highest rate in a building in Izmir.
Keywords: TS 825, energy consumption in buildings, window alternatives, energy efficiency, design of experiment

1.Introduction

In recent years, factors such as global warming and energy crisis in the world have caused many countries to experience developments in the effective and efficient use of energy. Especially after the oil crisis in the 1970s, there has been a significant sensitization about energy consumption worldwide. With the increasing energy and environmental awareness, the Kyoto protocol was signed in 1997 in Kyoto. (UNFCCC, 1997) In the following process, many laws, regulations and certification systems have been developed in order to reduce energy dependency in the world.

Since the beginning of the 1990s, with the determination that more than 50% of the energy used in the world is used in buildings, solutions to minimize energy use in buildings have started to be studied (Erengezgin, 2005). As the building sector is one of the leading sectors in terms of energy consumption, steps towards creating living conditions in comfortable and healthy spaces made by various regulations, directives, etc. started to be taken with studies, while reducing the energy use in buildings. (Aşikoğlu et al.,2021) One of the most important steps taken in Europe in this regard is the Energy Performance of Buildings Directive (EPBD) numbered 2002/91/EC published by the European Union on. The purpose of this directive is to promote the improvement of energy performance, indoor climate requirements and cost effectiveness of buildings, taking into account the climate and local conditions of the member states. (EPBD, 2002) In the EPBD-recast numbered 2010/31/EU published by the European Union, it is stated that energy consumption in the building sector in Europe constitutes 40% of the total energy consumption. In order to reach the European

Union's target of reducing energy consumption by 20%, the need to increase energy efficiency is emphasized. (EPBD, 2010)

In the long-term renovation strategy set out in Directive (EU) 2018/844 (EU, 2018), published by the European Union, as a revision of Directives 2010/31/EU and 2012/27/EU, each Member State should determine a roadmap for increasing the national stock of highly energy efficient and decarbonized buildings, ensuring the cost-effective transformation of existing buildings into almost zero-energy buildings, and reducing greenhouse gas emissions by 80%-95% compared to 1990 (EU, 2018).

According to the EPBD, cost-effectiveness is as important as energy efficiency in buildings. The legal procedure for cost-effective energy efficiency, which is of great importance for Turkey, which imports approximately 80% of its energy, has not yet been established. However, it is critical that this work is carried out by experts as soon as possible, both economically and socially (Ganiç, 2012).

In this process, in parallel with the developments in Europe, various legal arrangements have been made in Turkey, which has a high dependence on foreign energy, with the aim of using energy effectively and efficiently in buildings. The "Energy Efficiency Law", which is a turning point in the developments in this direction in Turkey, was adopted in 2007 and entered into force after being published. "The purpose of this Law is to increase efficiency in the use of energy resources and energy in order to use energy efficiently, prevent waste, alleviate the burden of energy costs on the economy and protect the environment" (Energy Efficiency Law, 2007).

Another important step taken for this purpose is the "Regulation on Energy Performance in Buildings" published in 2008. In the Regulation on Energy Performance in Buildings, important issues such as the annual heating energy requirement of the building should be less than the limit value specified in the TS 825 standard, the rules regarding the "U" values determined for the walls, floors and floors separating the heated volumes, ceilings and roofs forming the building envelope for each climate zone (Regulation on Energy Performance in Buildings, 2008). In Turkey, TS 825 standards are used to describe the limit values to be complied with in the Regulation on Energy Performance in Buildings (TS 825, 2008). It is indicated that there are 4 climate zones in Turkey and the thermal conductivity (U values) requirements for walls, roofs, floors and windows for 4 building elements considered according to climate zones are specified in TS 825.

Table 1- U-value requirements for walls, roofs, floors and windows according to the climate zones specified in TS 825 (TS 825, 2008)

TS 825 climate zones	Wall [W/(m²K)]	Roof [W/(m²K)]	Ground [W/(m²K)]	Window [W/(m²K)]
1	0,7	0,45	0,7	2,4
2	0,6	0,4	0,6	2,4
3	0,5	0,3	0,45	2,4
4	0,4	0,25	0,4	2,4

2. Case Study

This study is based on a case study in which the sample building in TS 825 is insulated according to the limit values of the 1st climate zone in TS 825 where Izmir province is located. The case study is at the coordinates 38.4237° N, 27.1428° E and the height above sea level is 12 m. The floor area of the building is 326,21 m^2, total area is1715,56 m^2 and net usable area is1379,84 m^2. It consists of 4 floors including the basement and a roof space. The roof space of the building is 236,81 m^2. Floor plans and sections of the case study are shown in Figure-1 and Figure-2.

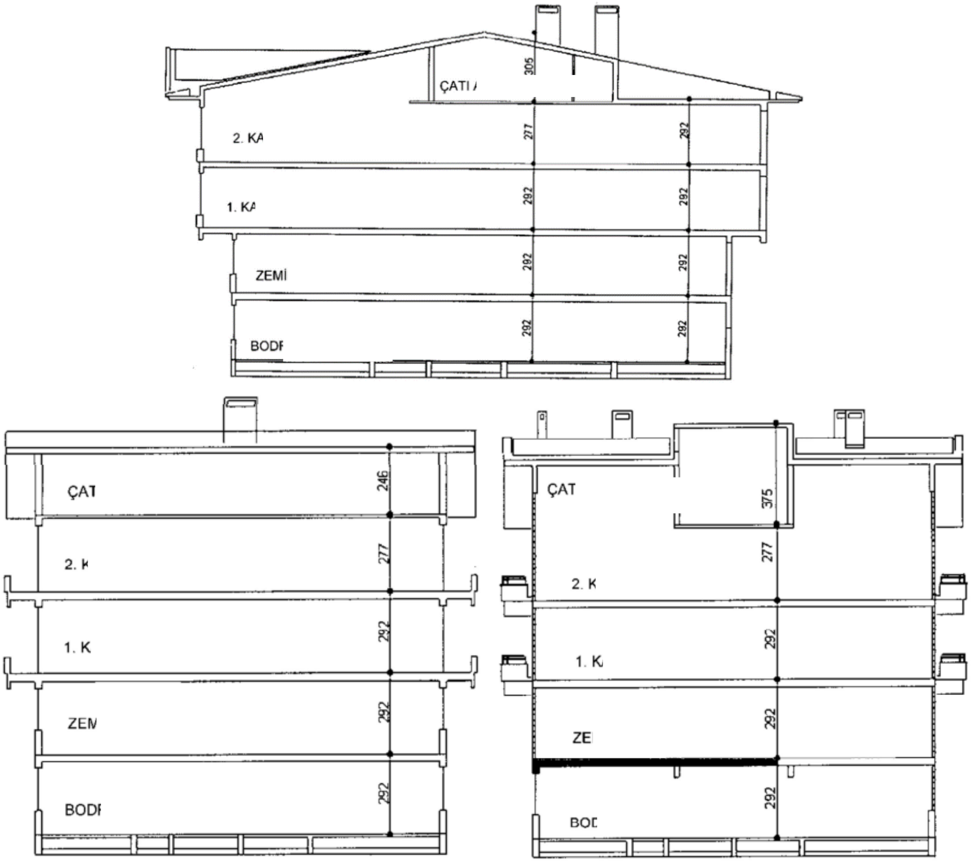
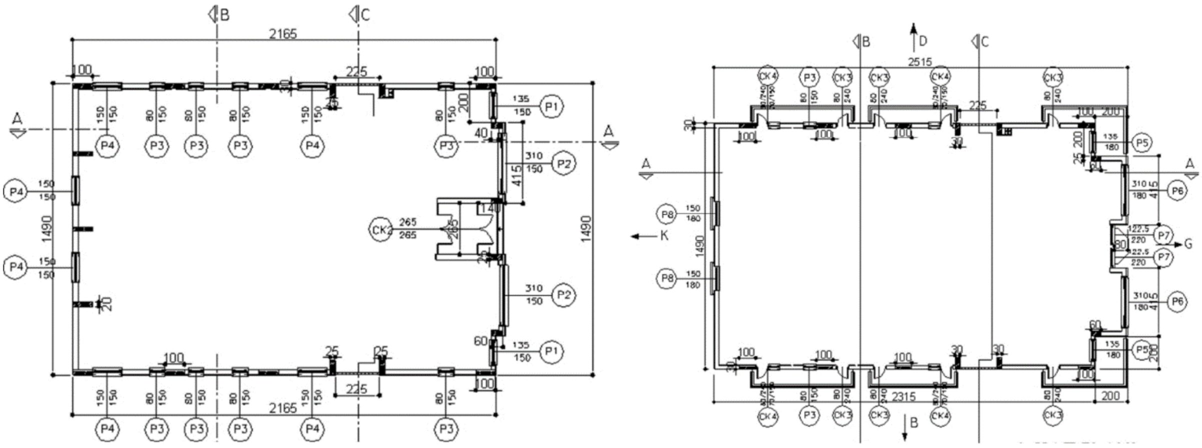


Figure 1- AA, BB, CC sections of the case study



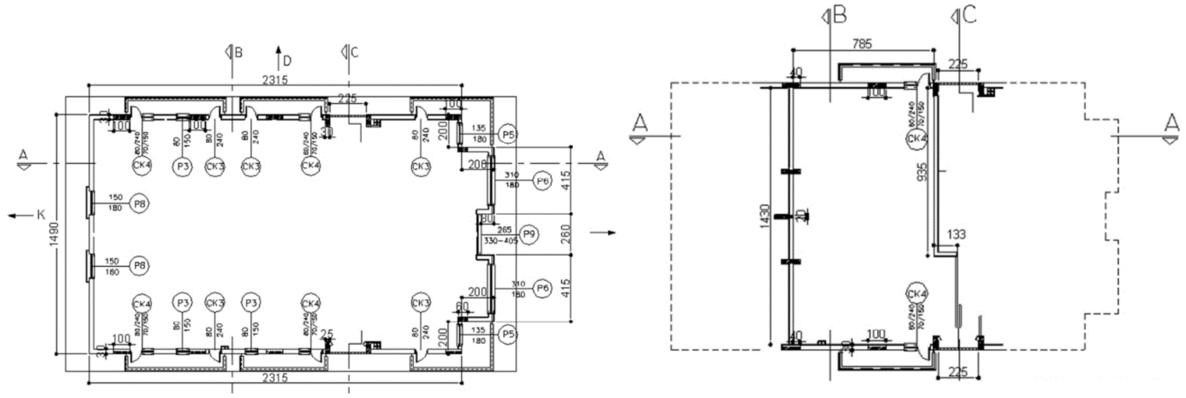


Figure 2- Basement, ground, first, second and roof plans of the case study

The structural system of the building is reinforced concrete system. The building has an occupied pitched roof in a partial area. Occupied pitched roof is covered with tiles. In order to adhere to Ts 825 limit values, in this study, thermal insulation was made under the tile in the occupied pitched roof and above the slab in the flat roof. Brick and plaster were used on the exterior walls and thermal insulation was applied. On the ground, thermal insulation was applied on top of the cast concrete. Accordingly, the U-value of the walls of the case study were modeled as 0.7 W/m^{2}K, the roof as 0.45 W/m^{2}K and the floor as 0.7 W/m^{2}K. And the building components thermal spesifications shown in Table 2.

Table 2- Building components thermal spesifications

	Material	**Width (cm.)**	**Conductivity (W/mk)**	**Spesific Heat (J/kgK)**	**Density (kg/m^3)**
	Gypsum insulating plaster	2	0,18	1000	600
	XPS Extruded Polystyrene	3	0,03	1400	35
	Brick	19	0,72	840	1920
Exterior wall	Gypsum insulating plaster	2	0,18	1000	600
U-Value (W/m^{2}K)			0,604		
	Ceramic	1	1,3	840	2300
	Floor/Roof screed	5	0,41	840	1200
	Asphalt ins. Role	0,5			
	XPS Extruded Polystyrene	7	0,41	840	1200
	Concrete, Reinforced	12	0,41	840	1200
Flat roof	Plaster	2	0,72	840	1760
U-Value (W/m^{2}K)			0,435		
	Clay Tile	2,5	1	800	2000
	Asphalt ins. Role	0,5			
Pitched roof	Glass fibre/wool	8	0,04	840	12
	Plywood panels	0,5	0,09	1880	460
U-Value (W/m^{2}K)			0,45		
	Marble	3	2,9	840	2750

Ground floor	Floor/Roof screed	3	1,13	1000	2000
	Asphalt ins. Role	0,5			
	XPS Extruded Polystyrene	3	2,8	1000	2600
	Cast concrete	10	1,13	1000	2800
U-Value (W/m^2K)			0,69		

3. Methodology

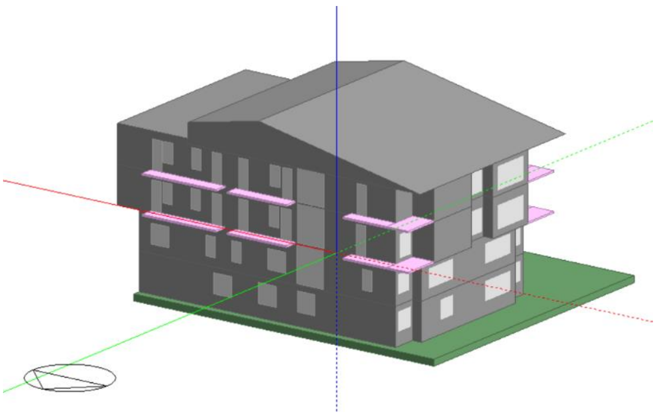
In the study, the effects of the ratio of windows on the facades, the thermal transmittance of the window, frame type and the use of shading elements on total energy consumption were investigated. Different scenario combinations were created using various variables related to the windows in the case study. The case study was modeled with the Design Builder and then scenarios determined with design of experiment were applied to the model. Based on the energy consumption values obtained for each scenario, the effects of the variables on energy consumption were determined with factorial design analyses. The limit of this study is to evaluate the effect of parameters in windows on energy consumption within the framework of the limit U-values specified in TS 825, using the climate data of Izmir province.

The method followed in this study,

- Modelling the case study
- Selection of factors and levels
- Creation of scenario combinations with full factorial experimental design
- Simulation
- Analysis of the data.

4. Modelling and energy analysis

There are many energy simulation software to determine energy consumption in buildings. DesignBuilder used in this study is a program with EnergyPlus interface designed to determine energy performance, comfort and lighting performances in buildings. EnergyPlus is a 3rd generation simulation program used for heating, cooling, ventilation, lighting and comfort criteria in buildings (Fotopoulou et al., 2018). Design Builder with EnergyPlus interface is a modeling environment that enables simulation of a range of data such as energy consumption, carbon emissions, comfort conditions, daylighting, HVAC, etc. (URL-1).



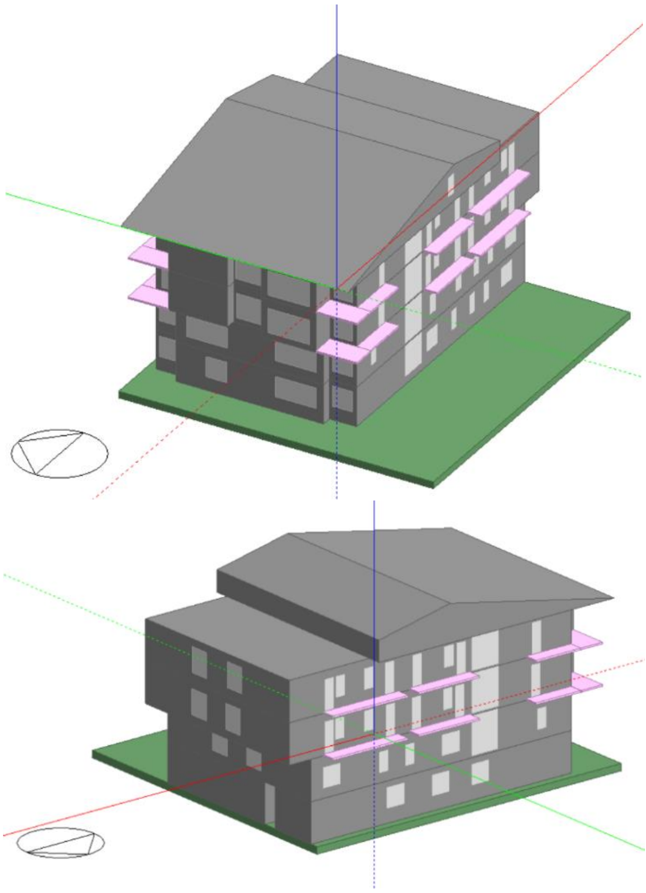


Figure 3- The model of the case study

After the case study was modeled with the design builder simulation program, different scenarios determined for the windows were applied to the model. At this stage, 4 factors were determined for the windows in the case study, window ratios, whether or not shading elements are used, the thermal transmittance value of the window and the materials of the frame. For each factor, two levels were determined for the use of different materials, such as none, more or less, low or high. The explanations of the factors, their level alternatives and the numerical equivalents of the factor levels are shown in Table 3.

Table 3- The explanations of the factors, their level alternatives and the numerical equivalents of the factor levels

Parameters	**1.level (-)**	**2. level (+)**
Window ratio	% 100 ratio	%75 ratio
U-value	Air filled double glazing	Argon filled triple glazing
Frame material	Wooden frame with no thermal brick (3,633 W/M2k)	Aluminum frame with no thermal brick (5,581 W/m2K)
Shading	Non used	Used (Blind with high reflectivity slats)

The combinations of all levels of all factors were generated as a full factorial orthogonal array using SPSS software. In this study, all alternatives were tested by combining each level of each parameter with each other. Factorial design is an experimental design method developed by Fisher and Yates, designed to detect the main effects and interaction effects of parameters at the same time (Şenoğlu and Acitaş 2014, p:147). Factorial designs are an experimental design method based on orthogonal arrays, algebra and group theories created by row-column (Yates)-block designs (Kobilinsky et al., 2017)

In the literature, the process of designing an experiment is described as: recognition and expression of the problem, selection of the response variable, selection of factors, levels and intervals, determination of the independent variables (factors) and levels that cause state change in the response variable, selection of experimental design, conducting the experiment, statistical analysis of the data, graphical representation and evaluation of the results. (Durakovic, 2017), (Montgomery, 2005).

It has been found that with the results obtained through design of experiments, optimum or near-optimal results can be achieved in all cases (Gong. Cai and Jiang, 2008). (Leung and Wang, 2001). (Sharma et al., 2005). (Mandal et al., 2008). (Ge et al., 2012). (Li et al., 2006). With using experimental design in the field of architecture; the effect degrees and the most effective levels of the selected parameters on the result were determined. (Aşikoğlu, 2022) Separate simulations were performed and total annual energy consumption values were obtained. The energy consumption values obtained for 16 different scenarios are shown in Table 4.

Tablo 4- Energy consumption values for 16 different scenarios

Simulation	Window ratio	U-value	Frame material	Shading	Enegy consumption (kWh)
1	-	-	-	-	27.165
2	+	-	+	-	26.063
3	-	+	-	-	25.894
4	+	+	-	-	24.835
5	+	+	+	+	25.192
6	+	-	+	+	26.325
7	+	-	-	-	25.949
8	+	+	-	+	25.096
9	-	+	+	-	25.992
10	+	-	-	+	26.214
11	+	+	+	-	24.928
12	-	-	+	+	27.463
13	-	+	-	+	26.089
14	-	-	-	+	27.350
15	-	-	+	-	27.282
16	-	+	+	+	26.191

5. Analysis of data
Obtained results were evaluated statistically. While evaluating the results, "Analyze Factorial Design" in the Minitab program was used. The statistical outputs obtained as a result of the factorial design analysis performed by the Minitab program are shown below;

- Coded Coefficients

- Analysis of Variance
- Regression Equation in Uncoded Units
- Pareto chart
- Residual plots (normal probability plot, main effect plot etc.) (URL-2)

First, Analysis of Variance was performed to determine the significance level of the effect of each parameter on the result (Table 5). The P values of each parameter were examined to determine the effects of the window parameters on the total energy demand separately. Based on the fact that the parameters with a P value less than 0.05 have an effect on the result, it can be said that all parameters have a significant effect on energy consumption.

Table 5- Analysis of Variance from Minitab

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	10	10896399	1089640	82660,84	0
Linear	4	10868762	2717190	206127,97	0
Window ratio	1	4866315	4866315	369162,03	0
U-value	1	5752814	5752814	436412,51	0
Frame Material	1	44318	44318	3361,97	0
Shading	1	205315	205315	15575,37	0
2-Way Interactions	6	27637	4606	349,43	0
Window ratio*U value	1	21903	21903	1661,6	0
Window ratio*Frame material	1	16	16	1,22	0,321
Window ratio*Shading	1	5389	5389	408,79	0
U-value*Frame material	1	285	285	21,6	0,006
U-value*Shading	1	44	44	3,35	0,127
Frame material*Shading	1	0	0	0	0,955
Error	5	66	13		
Total	15	10896465			

Design of experiments methods provide statistical and graphical tools to analyze the results. Main effect plots are the basic graphical representation of the direction and magnitude of the response with respect to the factor as a function of factor levels (Mahieux, 2005). In main effect plots, if the line for a given parameter is close to horizontal, the parameter has no significant effect. On the other hand, a parameter where the line has the highest slope will have the most significant effect (Sahoo, 2012). (Antony, 2014), (Xin, 2013), (Vignesh and Ramanujam, 2020).

Pareto plots show the effects of parameters on the outcome and interaction effects. The figure shows the Pareto graph and main effect graphs of the results. When the graphs are analyzed (Table 6), it is seen that window insulation, window ratio, shading element and frame material affect the total energy requirement from most to least, respectively.

Table 6- Pareto chart, probability and main effect analysis for case study made with Minitab

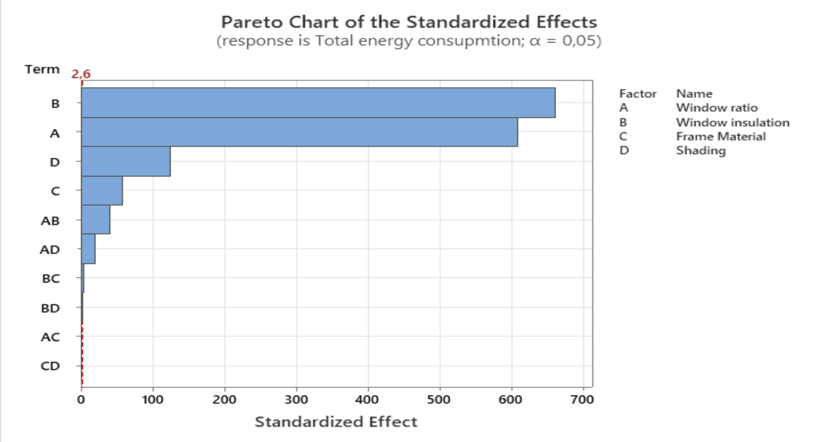
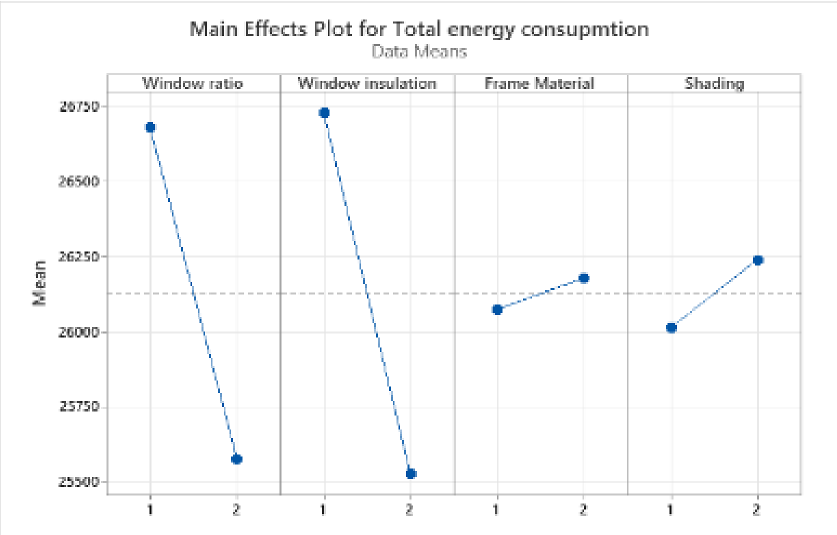
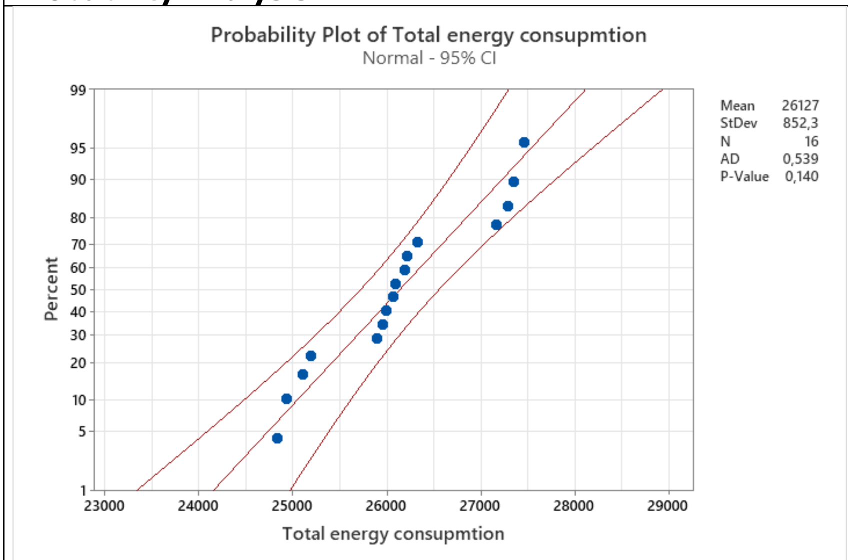
<table>
<tr><th>Effect Analysis</th><th>Interpreting the results</th></tr>
<tr><td>
</td><td>Pareto chart of the effects shows, the highest effect on the energy consumption is window insulation. The effects for the interactions and frame material are the lowest.</td></tr>
<tr><td>
</td><td>Main effect plots for total energy consumption shows, differences between factor alternatives. All the parameters affect the result in this study. Since the steepest line is the window insulation, it represents the highest effect. Because of the direction of the line, window ratio and window insulation have a negative effect, and frame material and window ratio positive effect.</td></tr>
<tr><th>Probability Analysis</th><th>Interpreting the results</th></tr>
<tr><td>
</td><td>Probability analysis graph shows, the data points are close to the fitted normal distribution line (the middle line of the graph). The distribution of the data set is suitable in the study.</td></tr>
</table>

Table 7- Coded Coefficients from Minitab

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		26126,7	0,9	28784,17	0	
Window ratio	-1102,986	-551,493	0,908	-607,59	0	1
U-value	-1199,251	-599,626	0,908	-660,62	0	1
Frame Material	105,259	52,629	0,908	57,98	0	1
Shading	226,559	113,279	0,908	124,8	0	1
Window ratio*U-value	73,999	36,999	0,908	40,76	0	1
Window ratio*Frame material	-2,001	-1,001	0,908	-1,1	0,321	1
Window ratio*Shading	36,704	18,352	0,908	20,22	0	1
U-value*Frame material	-8,436	-4,218	0,908	-4,65	0,006	1
U-value*Shading	3,324	1,662	0,908	1,83	0,127	1

Probability plot is a graphical technique used to assess whether a data set follows a particular distribution (Chambers et al., 1983). The Probability plot, which expresses the suitability of the distribution of the data set obtained as a result of the study, is shown in the Table 6.

The regression equation expressing the effect of window parameters on energy demand, obtained using the Minitab statistical program, is shown below;

Regression Equation

Total energy consupmtion =*29549,0 - 1405,09 Window ratio - 1429,91 Window insulation*
+ 136,25 Frame Material + 106,15 Shading
*+ 148,00 Window ratio*Window insulation*
*- 4,00 Window ratio*Frame Material + 73,41 Window ratio*Shading*
*- 16,87 Window insulation*Frame Material*
*+ 6,65 Window insulation*Shading + 0,22 Frame Material*Shading*

According to this equation, it can be stated that the decrease in the window ratio and the increase in window insulation have a positive effect on reducing energy demand, while the choice of wooden frame and the use of shading elements have a negative effect.

CONCLUSION

In this study, the effect of changes in the windows of a building in Izmir province, which has been retrofitted within the framework of TS 825 limit thermal conductivity values, on the total energy consumption is investigated. In the study, only one of the 4 climate zones in Turkey was evaluated using climate data. Therefore, it is possible to reach different results for different climate zones in Turkey. For Izmir, according to the results obtained with the changes made in the parameters determined in the windows of the model, the parameter that provides the highest level of annual energy savings is provided by using low U-value windows. Following this, it was determined that a significant amount of energy savings can be achieved by reducing the window ratio in the existing model by 25%.

In the building designs to be constructed in Izmir province, it is obvious that the window ratio in the facades has an effect on energy consumption as much as the U-value of the windows. For this reason, the window ratios to be given at the design stage affect the energy consumed during the useful life of the building. In this sample, the choice of shading elements and window frame materials were secondary to other parameters. Since shading elements greatly increase the heating energy requirement in winter, their effect on the total energy consumption was negative. Considering the most effective levels of the parameters in the application, it can be said that the model with 25% less window ratio, high insulation, wooden frame without shading elements has the lowest energy consumption.

According to the results;

- According to the energy consumption values for the scenarios (Table 4); It was determined that the lowest annual energy consumption was 24.835 kWh at the 4. Scenario and the highest annual energy consumption was 27.463 kWh at the 12. scenario. The combination of parameters in scenario 4 is as follows; 75% window ratio, argon filled triple glazing, wooden frame without thermal brick (3,633 W/m^{2}K), no shading. The combination of parameters in scenario 4 is as follows; 100% window ratio, air-filled double glazing, aluminum frame without thermal brick (5.581 W/m^{2}K), high reflectivity strips shading roller blind

- Probability plot of total energy consumption; the suitability and homogeneous distribution of the selected data set are shown on Figure 7. According to the Analysis of Variance (Table 5); since the p value of all parameters is <0.05, it can be said that each of them has a significant effect on the result. In interaction effects; no significant effect was detected for window ratio* frame material, U-value* frame material, U-value* shading.

- In the Coded Coefficients analysis shown in the Table 7, it was determined that the window ratio and U-value parameters had a negative effect, frame material and shading parameters had a positive effect on energy consumption. Since the results are evaluated in terms of energy consumption, it can be said that the parameters that affect negatively reduce energy consumption, while parameters that affect positively increase energy consumption

- As shown in the Main effects plot for total energy consumption and the Pareto chart of the standardized effects (Table 6); It was determined that the effect levels of Window ratio U-value factors on the result were higher, and the effect levels of Frame Material and shading factors on the result were lower. In the Main effect diagram, the closer the line of a factor is to the vertical, the higher its effect on the result, and the closer it is to the horizontal, the lower it is. Direction of diagrams are used to determine whether parameter has a positive or negative effect on the energy consumption.

With the method followed in the study, it will be possible to make appropriate parameter selections for different building types in different climate zones.

REFERANCES

Antony, J. (2014). *Design of experiments for engineers and scientists*. Elsevier.

Aşikoğlu, A. (2022). *Pasif ev standartlari doğrultusunda mevcut binalarin iyileştirilmesi amaçli bir istatistiksel yaklaşim önerisi.* Dokuz Eylül Üniversitesi, Doktora Tezi.

Aşikoğlu, A., Altin, M., & Bayram, N. S. (2021). Pasif Ev Sertifika Sisteminin Mevcut Binalarda Uygulanmasi: EnerPHit Sertifika Sistemi. *Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi*, *21*(5), 1146-1156.

Durakovic, B. (2017). Design of experiments application, concepts, examples: State of the art. *Periodicals of Engineering and Natural Sciences*, *5*(3).

Energy Efficiency Law, "Enerji Verimliliği Kanunu", (2007). 11 Nisan 2020, https://www.resmigazete .gov.tr/eskiler/2007/05/ 20070502-2.htm

Erengezgin, Ç. (2005). Enerji mimarliği. *Ege Üniversitesi Güneş Enerjisi Enstitüsü*, *4*, 47-48.
EU, Directive 2010/31/EU. *European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (recast)*, Off. J. Eur. Union (2010) 13–35.
EU Commission Report, (2013). *Progress by Member States towards Nearly Zero-Energy Buildings.*
EU, *Directive 2018/844/EU.* (2018). 22 Temmuz 2021, https://eurlex.europa.eu/legalcontent/EN/TXT/?uri=uriserv%3AOJ.L_.2018.156.01.0075.01.ENG
EU, *Directive 2021/0203 (2021).* Directive Of The European Parliament And Of The Council on Energy Efficiency (Recast)
Fotopoulou, A., Semprini, G., Cattani, E., Schihin, Y., Weyer, J., Gulli, R., & Ferrante, A. (2018). Deep renovation in existing residential buildings through façade additions: A case study in a typical residential building of the 70s. *Energy and Buildings*, *166*, 258-270.
Ganiç, N. (2012). *Minimum enerji performans gereksinimlerine ilişkin optimum maliyet düzeyinin ofis binalarindaki iyileştirmeler için hesaplanmasi*. İstanbul Teknik Üniversitesi, Yüksek Lisans Tezi.
Ge, Z., Gao, Z., Sun, R.ve Zheng, L. (2012). Mix design of concrete with recycled clay-brick-powder using the orthogonal design method. *Construction and Building Materials*, *31*, 289-293.
Gong, W., Cai, Z.ve Jiang, L. (2008). Enhancing the performance of differential evolution using orthogonal design method. *Applied Mathematics and Computation*, *206*(1), 56-69.
Kobilinsky, A., Monod, H. ve Bailey, R. A. (2017). Automatic generation of generalised regular factorial designs. *Computational Statistics ve Data Analysis*, *113*, 311-329.
Mahieux, C. A. (2005). *Environmental degradation of industrial composites*. Elsevier.
Leung, Y. W. ve Wang, Y. (2001). An orthogonal genetic algorithm with quantization for global numerical optimization. *IEEE Transactions on Evolutionary computation*, *5*(1), 41-53.
Li, H., Jiao, Y. C., Zhang, L. ve Gu, Z. W. (2006, September). Genetic algorithm based on the orthogonal design for multidimensional knapsack problems. In *International conference on natural computation* (pp. 696-705). Springer, Berlin, Heidelberg.
Mandal, V., Mohan, Y. ve Hemalatha, S. (2008). Microwave assisted extraction of curcumin by sample–solvent dual heating mechanism using Taguchi L9 orthogonal design. *Journal of pharmaceutical and biomedical analysis*, *46*(2), 322-327.
Montgomery, D. C. (2005). *Design and analysis of experiments*. John wiley & sons.
Regulation on Energy Performance in Buildings, "Binalarda Enerji Performansi Yönetmeliği", (2008). 04 Mayis 2021, https://www.resmigazete.gov.tr/eskiler/2008/12/20081205-9.htm
Sahoo, P. (2012). Tribological performance of electroless Ni-P coatings. In *Materials and Surface Engineering* (pp. 163-205). Woodhead Publishing.
Sharma, P., Verma, A., Sidhu, R. K. ve Pandey, O. P. (2005). Process parameter selection for strontium ferrite sintered magnets using Taguchi L9 orthogonal design. *Journal of materials processing technology*, *168*(1), 147-151.
Şenoğlu, B. ve Acitaş, Ş. (2011). *İstatistiksel deney tasarimi: sabit etkili modeller*. Nobel.
TS 825 Binalarda Isi Yalitim Kurallari, Aralik 2013.
UNFCC, *Kyoto Protocol To The United Nations Framework Convention On Climate Change*, (1997). https://unfccc.int/sites/default/files/resource/docs/cop3/l07a01.pdf#page=24
Xin, Q. (2013). Optimization techniques in diesel engine system design. Diesel engine system design. *Diesel Engine System Design,* 203-296.
Vignesh, M. ve Ramanujam, R. (2020). Laser-assisted high speed machining of Inconel 718 alloy. In *High Speed Machining* (pp. 243-262). Academic Press.

Chambers, J. M., Cleveland, W. S., Kleiner, B., & Tukey, P. A. (2018). *Graphical methods for data analysis*. Chapman and Hall/CRC.

URL LINKS

URL-1 Design Builder, https://designbuilder.co.uk (Acces Date: 04.05.2021)
URL-2 Minitab, https://support.minitab.com/en-us/minitab/20/help-and-how-to/statistical-modeling/doe/how-to/factorial/analyze-factorial-design/before-you-start/example/ (Acces Date: 04.10.2022)