AN ENERGY PERFORMANCE BASED DECISION SUPPORT SYSTEM FOR NORTH FACING SETTLEMENTS

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ABSTRACT

The energy-efficient building design process is an iterative process in which many parameters that can affect the energy loads of the buildings are observed. It is known that the decisions taken during the early design stage have an impact on the energy consumed by the buildings during the production and usage stages. While considering the effect of building design parameters on building energy performance, it is necessary to analyze the effect of the parameters to make decisions among many parameters. Decision support systems are needed when decisions should be made by considering multiple parameters to improve the energy performance of the buildings, especially when building design parameters have a limiting effect on energy efficiency. In energy-efficient design, wide facades of buildings are expected to be oriented to the south, especially in cold and temperate climatic regions where the heating period is longer, while in regions where the view is to the north, wide facades of the buildings may be oriented to the north. It is seen that the orientation to the view has a limiting effect on the orientation to optimize the solar radiation gain for energy efficiency. Situations with such limiting effects may appear as design problems where the effect of more than one parameter should be considered. In this study, it is aimed to produce optimum solutions in non-optimally oriented buildings. For this purpose, it has been studied to analyze the design parameters of the residential buildings oriented to the north and to determine the facade proposals to reduce the energy loads. To accomplish this, first generating the building energy model, then the sensitivity analysis of the facade design parameters, and finally optimization of the annual heating energy loads, cooling energy loads, and CO_2 emissions has been taken into account. Sensitivity analysis and optimization methods are decision support systems for solving problems that involve evaluation according to multiple criteria. With the optimization results, it is expected to produce an output in which all the facade parameters are considered together in the non-optimal orientated residential buildings.

INTRODUCTION

The amount of energy consumed by buildings in the production and use stages covers a large part of the total energy consumed in the world. Since the buildings produced to fill the housing gap are produced in large numbers, the decisions to be taken at the design stage affect numerous houses and users. For this reason, energy conservation gains importance in interventions to fill the housing deficit in cities compared to single buildings. Especially, it is important to focus on energy efficiency approaches in the design stage of buildings in solving energy problems.

Climatic design is one of the approaches that aim to design buildings in an energy-efficient manner. Climatic conditions related to the external environment and parameters related to the built environment such as location, orientation, building form, space organization, building envelope (facade), natural ventilation, natural lighting, and solar control are the parameters that are effective in climatic design. The climatic conditions of the external environment and the location parameter are often not under the architect’s control in the design process, and design parameters related to the built environment may have limiting effects on climatic design. For this reason, the design process becomes a repetitive process in which many criteria are observed. To make a choice when multiple criteria are observed, decision support systems are required to improve the energy performance of the building (Tavares and Martins, 2007).

The decision support systems for building energy efficiency are; simulation-based, multi-criteria decision-making systems, sensitivity analysis, and multi-objective optimization (Solmaz et. al., 2016). Simulation-based approaches are based on the generation of energy models of buildings using simulation methods and the selection of the best solution among various scenarios. Multi-criteria decision-making methods are used in the decision-making process allowing a finite set of alternatives to be explored for building energy efficiency (Roulet et al., 2002). Sensitivity analysis methods show the input-output relationships to identify the most effective input parameters and categorized into two groups as local and global (Saltelli et al., 2004). The local sensitivity analysis method is based on an approach where the importance of a design parameter is evaluated while all other parameters are kept constant. In global sensitivity analysis, while the importance of a design parameter is evaluated, all other parameters change simultaneously (Ulukavak Harputlugil, 2009). Multi-objective optimization is an optimization problem that can be used to analyze the trade-off relations between multiple objectives to optimize building energy performance by providing a set of solutions (Asadi et al., 2014).

These systems guide the designer in making a choice based on the effect of design parameters on energy performance outputs. There are many studies aiming to provide decision support at the early design stage in increasing the energy performance of buildings. (Nguyen, 2013; Yıldız et. al., 2012; Gerçek and Arsan, 2019). However, it has been determined that there is a gap in providing decision support in cases where the climatic design is limited by the parameters of the built environment. Generally, in climatic and energy-efficient design, it is important to orient the wide facades of buildings to the south (in the northern hemisphere) to optimize solar radiation gain, especially in cold and moderate climatic regions where the heating period is longer (Berköz et. al., 1995). However, there may be cases where the buildings are oriented to the north since the view is to the north. Samsun city in the Black Sea region is an example of this situation. In Samsun, which grew linearly parallel to the sea with the increase of housing need, orientation towards the view (north) dominated. To reduce energy losses, in this study it is aimed to optimize heating energy loads, cooling energy loads, and CO_2 emissions with facade design parameters in non-optimal north-oriented buildings.

In line with this goal, a decision support approach was applied by using regression-based sensitivity analysis and simulation-based optimization methods. The method of the study consists of generating the building energy model with the Design Builder program, determining the facade design parameters (orientation, window height, width, solar heat gain coefficient, and U value, thermal insulation material specific heat value, thickness, and thermal conductivity value, shading device depth, and angle, and air infiltration rate), determining the most effective design parameters by sensitivity analysis with Energy Plus and jEPlus programs and optimizing the heating energy loads, cooling energy loads and CO_2 emissions with jEplus+EA program. With the optimization results in this decision support approach, it is expected to produce an output in which facade parameters are considered together in the north-facing residential buildings.

METHODOLOGY

In this study, an optimization-based decision support approach for non-optimal oriented residential buildings is suggested with sensitivity analysis and simulation-based optimization to select the optimum façade solution set which minimizes the heating energy loads, cooling energy loads, and CO_2 emissions. The proposed method consists of three stages: Generating the Building Energy Model, Application of Sensitivity Analysis, and Application of Optimization.

The first stage, generating the building energy model, includes the production of the energy model with the simulation program to obtain the outputs of the energy performance of the housing model produced within the scope of the study. To generate the energy model of the building, the Design Builder program, which was produced to measure and control the building energy performances, was used (Altensis, 2021). The building energy model generated with the Design Builder program has been converted to an idf file to be used in the EnergyPlus program. The EnergyPlus program is a building energy simulation program developed by the US Department of Energy to create building energy models (Energy Plus, 2021).

In the second stage, sensitivity analysis was performed by defining the input parameters for the sensitivity analysis, generating the input files, generating the simulation results, and determining the effect levels of the input parameters on the energy loads. Sensitivity analysis has been defined as a measure of the effect of a particular input on output (Saltelli et al., 2004). With the sensitivity analysis stage, it is aimed to understand the effect of facade design (input) parameters on building energy performance outputs. With this method, significant support is provided to the designer in understanding the cause-and-effect relationship between parameters and simulation results (Şenel Solmaz, 2015). In the study, global sensitivity analysis was preferred because each parameter can be analyzed simultaneously, and the regression-based method which is the most common method used in building energy analysis studies, is preferred because it is a fast-calculated method and easy to understand (Tian, 2012).

The first step in performing the sensitivity analysis is to define the design parameters. Then, the value ranges of the defined parameters are determined. The values of the design parameters can be assigned with different sampling methods, the Latin Hypercube sampling (LHS) was used in the implementation of the proposed model. LHS is a widely used method due to its stratification properties (Tian, 2012). In the sensitivity analysis, after defining the parameters and determining the value ranges, values were assigned to these parameters by the LHS method on the base model, and input files were created. The jEPlus program is used to create input files, which was first introduced as a parametric tool for EnergyPlus in 2009 (Zhang and Korolija, 2010). By using the idf file obtained through the EnergyPlus program, multiple simulations of the files were made with the LHS method in the jEPlus program. The simulation was concluded by the program giving values simultaneously to each parameter it had defined. Sensitivity analysis results were obtained by entering the simulation results into the jEPlus+EA program which was published first by Yi Zhang in 2009 and it is powered by Java programming language (Zhang and Jankovic, 2017).

In the third stage, the application of the optimization was performed by determining the input parameters that will participate in the optimization by sensitivity analysis, generating material alternatives for the selected parameter, running the optimization, and determining the appropriate solutions. It is aimed to produce a set of facade design solutions with optimum heating and cooling energy loads and CO_2 emissions. Therefore, a multi-objective optimization problem with three object functions is used in this study. To find the optimal solutions in a shorter time, computer programs are used to search for a wide range of solutions. jEPlus+EA program was used in the optimization process with NSGA-II which is one of the most efficient genetic algorithms used in multi-objective optimization studies. jEPlus+EA program is chosen due to its full interactivity with on-the-fly adjustment of algorithm configuration, suitability for both single-objective and multi-objective problems, search space, optimization criteria, and the evaluation models. This program produces reliable optimization results for relatively low computational effort with a user-friendly interface. It has a simple JSON-based Application Programming Interface (API) providing complete control of the engine, data access for progress monitoring, solution inspection, and algorithm analysis (Zhang and Jankovic, 2017).

CASE STUDY

The study aimed to produce a building model to determine the facade solutions with optimum energy load results of the buildings that cannot be optimally oriented according to the characteristics of the climate zone. It is thought that determining the important parameters related to the facade by examining the effect levels of the facade input parameters on the energy loads of the buildings oriented to the north since the view is in the north direction in the northern regions of Turkey, and producing optimum facade alternatives according to these results will be effective in reducing the energy loads in the usege stage of the building. The building model is planned to be implemented in Samsun city, which is located in the Black Sea Region and has north-facing buildings with wide façade openings due to the sea view to the north.

Samsun city was located in a small lower bay on the Black Sea coast, after the 1970s it went out of the bay and continued its development along the coast with mostly industrial areas in the east and residential areas in the west (Yılmaz, 2004). Before 1970, Atakum, Atakent, and Kurupelit were summer resorts of Samsun city with beach areas, summer houses and recreational facilities on the coast, village settlements, and agricultural areas in the interior parts (Yılmaz, 2004).

Atakum region, which is planned as a summer resort and recreation area of the city; was quickly opened to the settlement with the rapid growth and due to the limited settlement area of the city. It is seen that the city development area determined by the municipality could not meet the needs, and the people determined the development area and the settlement area boundary expanded at a faster rate than expected (Uzuneminoğlu, 1992). The rapid development of Samsun in the direction of Atakum has led local administrations to invest in this region. Such investments have made Atakum even more attractive, and the city has spread rapidly, not only in the east-west direction but also from the coast to the south, with residences mostly built to take advantage of the sea view (Yılmaz, 2011).

With the growth of the city towards the Atakum region, the density in this part of the city, which grew linearly parallel to the sea, increased. In the region, buildings with wide façade openings in the direction facing the view dominated. The fact that the view is to the north results in the orientation of the living spaces to the north, in this region while the living areas should be oriented to the south in order to make optimum use of solar energy in the temperate humid zone. For this reason, a housing model in Samsun has been studied to optimize the heat losses of buildings with wide façade openings in the north direction.

Generating the Building Energy Model

Samsun is located in the temperate-humid climate zone. A Typical Meteorological Year (TMY) file was used in the data on the external climatic factors of Samsun (Crawley and Lawrie, 2021). The annual average temperature in Samsun is approximately 14.5°C, the annual average minimum temperature occurs in February and is 3.8°C, and the annual average maximum temperature is 27°C in August (Ministry of Agriculture and Forestry, 2021).

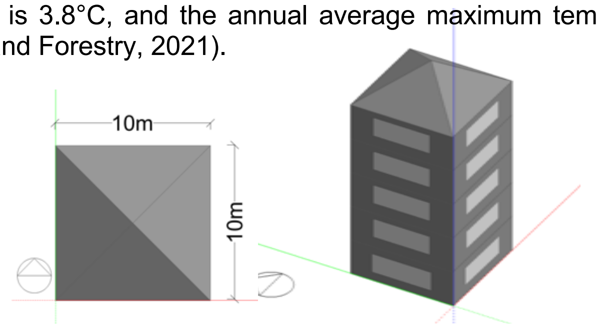


Figure 1. *Building energy model image from design builder program*

According to the statistical data of TurkStat, the building was modeled as five floors, since the number of residential floors built the most in Samsun between 2010-2019 was 5 floors (TurkStat, 2019). Since newly built houses in Samsun are mostly detached apartments, the building model is created as a detached apartment. The heating and cooling energy loads are calculated over the mezzanine. There is one flat on each floor and each flat is considered as a thermal zone. The building form is square and measures 10mx10m, and the floor area is 100m^2. The floor height is 3 m. The roof form is a hipped roof without eaves. The transparency ratio of the south, east and west facades of the model were determined as 30%, and the transparency ratio of the northern facade was determined as 80% to optimize the heat losses from the northern facade by considering the whole facade. It is assumed that there are no other buildings around the building (Figure 1).

Three users, one working two parents, and one child will be in the residence at certain times during the day. According to the 2021 data from the Turkish Statistical Institute, the average number of users per household in Samsun is 3.1-3.2 (TurkStat, 2021). For this reason, the number of users is determined as 3 for each flat. The heating system is determined as an individual natural gas heating system that will provide the indoor comfort temperature of 20ºC in the heating period, and the cooling system is determined as an individual wall type split air conditioner that will provide the indoor comfort temperature of 26ºC in the cooling period (T.C. Official Gazette, 2010). The blind, which is integrated to the outside as a shading element, is controlled to be active when the outside temperature is 24ºC and the average solar radiation value in the Design Builder program is 120 W/m^2. The data of the building envelope required for the definition and simulation of the model are at the values accepted in the TS825 thermal insulation standard calculation method in buildings. In other words, the upper limit values given in the TS 825 standard were taken into account in determining the building shell U values. The upper limit U values in the TS 825 standard are 0.60 W/m^{2}C for wall and floor, 0.40 W/m^{2}C for roof (Turkish Standard Institution, 2008). According to these value ranges, the wall U Value, floor U Value, roof U Value of the building were determined as 0.59 and 0.53 W/m^{2}C, respectively. Window U Value of the building is determined as 2.60 W/m^{2}C according to the catalog of the relevant window company.

Application of Sensitivity Analysis

The application of the sensitivity analysis method includes the stages of defining the input parameters, creating the input files, obtaining the simulation results, and determining the effect levels of the input parameters on the energy loads. The parameters defined in the first stage of the sensitivity analysis method are given in Table 1. Eleven parameters in five groups related to the façade were determined to be analyzed in the sensitivity analysis. Specified in the window title; window width, window height, solar heat gain coefficient (SHGC), total heat transmission coefficient (U value) parameters, specified in the exterior wall title; insulation material specific heat value, insulation material thickness, thermal insulation material thermal conductivity value parameters, specified in the shading element title; shading element depth and shading element angle parameters are discussed separately for each façade in the north-south-east-west order. Orientation and air infiltration rate were applied for the whole building. 36 input parameters were produced from the headings of orientation, window, exterior wall, shading element, and infiltration rate.

Table 1. *Design parameters and max. and min. value ranges of parameters*

Design (Input) Parameters		Code	Unit	Range
	Orientation	P1	degree	0,45,315
Window	Window Width	P2-P4	m	1.5-9.0
	Window Height	P5-P7	m	0.5-2.5
	Solar Heat Gain Coefficient (SHGC)	P8-P11	-	0.51-0.86
	Total Heat Transfer Coefficient (U Value)	P12-P15	W/m^2K	0.8-2.4
Exterior Wall	Insulation Material Thickness	P16-P19	m	0.01-0.1
	Insulation Material Specific Heat Value	P20-P23	J/kg-K	600-2000
	Insulation Material Thermal Conductivity Value	P24-P27	W/mK	0.03-0.04
Shading Element	Shading Element Depth	P28-P31	m	0.1-1.0
	Shading Element Angle	P32-P35	degree	10-90
	Infiltration	P36	ACH	0.1-1.0

After determining the value ranges that the defined input parameters will take, the values that the parameters will take in each file are assigned using the jEPlus program. While determining the maximum and minimum value ranges for each parameter, the limit values of the building materials commonly used in the construction industry and TS825 were taken into account (TSE, 2008).

In the jEPlus program, 300 files were created in such a way that each value of 36 parameters in the model changes simultaneously in each file. Outputs to be considered as performance indicators in this study are annual heating energy load (kWh) and annual cooling energy load (kWh). The next step is to determine the effect levels of the input parameters on the energy loads, in which the mathematical relations between the values assigned to the parameters and the simulation values are calculated according to these values. At this stage, by using the jEPlus+EA program, it will be possible to determine the effect levels of each parameter on the energy outputs. Within the scope of the study, the five most influential facade parameters that are effective on the annual heating energy load and annual cooling energy load are shown in Table 2.

Table 2. *The five most influential input parameters based on heating and cooling energy loads*

Heating Energy Load	Cooling Energy Load
Air Infiltration Rate	Window Width-East Facade
Window Width-South Facade	SHGC-North Facade
Window U Value-North Facade	Air Infiltration Rate
SHGC-South Facade	Window Width-South Facade
Window Width-East Facade	SHGC-East Facade

As can be seen in Table 2, the sensitivity analysis of the model was listed within the scope of the annual heating energy load and the annual cooling energy load, and the first five parameters with a high effect level were listed. In the findings obtained, the most effective parameters on the heating energy load are; air infiltration rate, window width-south facade, window U value-north façade, SHGC-south facade, window width-east façade; and the most effective parameters on the cooling energy load are; the window width-east facade, solar heat gain coefficient-north façade, the air infiltration rate, window width-south facade, and the SHGC-north façade

Application of Optimization

The application of the optimization consists of the steps of choosing the input parameters to be used in the optimization and defining the objective function. Optimization is a process that seeks the optimal solution according to the objective functions to be maximized or minimized (Attia et. al.,2013). Optimization problems can be classified as single-objective or multi-objective optimization problems according to the number of objective functions it aims to minimize (Nguyen et. al., 2014)

Multi-objective optimization aims that multiple objectives can simultaneously be considered by using algorithms that preserve trade-offs between two or more conflicting search objectives (Coello, 2006). The selection of the appropriate algorithms for a multi-objective optimization problem is important. Genetic algorithm is a part of the family of evolutionary algorithms which is one of the most popular algorithm techniques applied to building optimization problems (Nguyen et. al., 2014, Li et. al., 2017).

Non-dominated sorting genetic algorithm (NSGA-II) is a variation of the genetic algorithm used in the multi-objective optimization in building studies which are implemented to find trade-off relations among various objective functions (Naji et. al., 2021, Deb et. al., 2022). NSGA-II reduces the computational complexity and proposes a fast, non-dominated sorting algorithm (Jing and Du, 2020).

In the optimization phase, first of all, the design parameters to be used in the optimization were determined. The design parameters were analyzed in the same way as the parameters evaluated in the sensitivity analysis, but according to the results obtained in the sensitivity analysis, the most effective parameters on the heating and cooling loads were also detailed and added to the optimization. In the sensitivity analysis results, although the order of importance of the design parameters affecting the heating and cooling energy loads is different from each other, it is seen that the first five parameters in the order are mostly window width and solar heat gain coefficient. When the most effective parameters to create different building envelope component alternatives to be used in the optimization stage are examined, it is seen that these parameters are related to the window properties. Different building envelope component alternatives determined by changing the solar heat gain coefficient and window U value from the window properties are shown in Table 3 in descending order in terms of SHGC value.

Table 3. *Component alternatives developed considering the window properties*

No	Glass Type	Glass Layers	Surface	Fill	SHGC Value	U Value
Base	Uncoated	4+16+4	Clear glass	16 mm argon	0.78	2.6
1		4+12+4+12+4	Clear glass	12 mm air	0.71	1.9
2		4+16+4+16+4	Clear glass	16 mm argon	0.71	1.7
3	Heat control coated	4+12+4	Low-E glass	12 mm air	0.55	1.6
4		4+16+4	Low-E glass	16 mm argon	0.55	1.1
5		4+12+4+12+4	Low-E glass	12 mm air	0.48	0.9
6		4+16+4+16+4	Low-E glass	16 mm argon	0.48	0.6
7	Heat and sun control coated	4+12+4	Solar Low-E glass	12mm air	0.44	1.6
8		4+16+4	Solar Low-E glass	16 mm argon	0.44	1.1
9		4+12+4+12+4	Solar Low-E glass	12mm air	0.40	0.9
10		4+16+4+16+4	Solar Low-E glass	16 mm argon	0.40	0.6

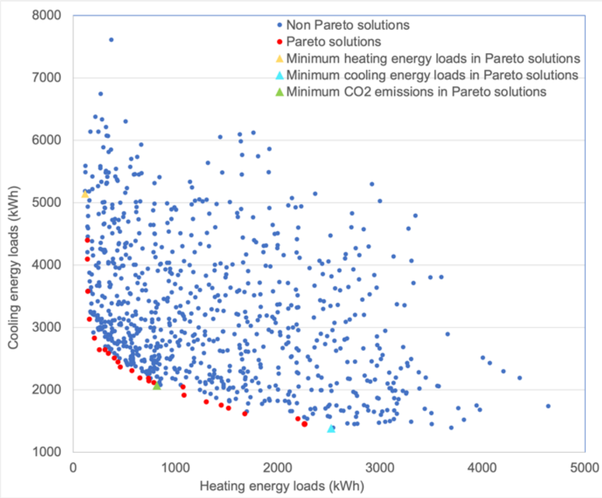
After the design parameters to be used in the optimization are determined, the objective function is defined. In this paper, heating energy loads, cooling energy loads, and CO_2 emissions are the three objectives that need to be considered simultaneously as a multi-objective optimization problem. jEplus + EA program is used to ensure the simultaneous optimization of these objectives. There are some parameter settings in the NSGA-II algorithm, including the population size, crossover rate, mutation rate, and iteration number. The recommended value range of the population size is 10~200, the crossover rate is between 0.4 and 0.99, the mutation rate is 0.0001~0.1, and the maximum generation is smaller than 1000 (Lei et al., 2005, Li et al., 2017). In this study; the population size of 10, the crossover rate of 0.9, the mutation rate of 0.1, and the iteration number of 92, the maximum generation of 200 are selected to get the best trade-off between the computational time and reliable solutions.

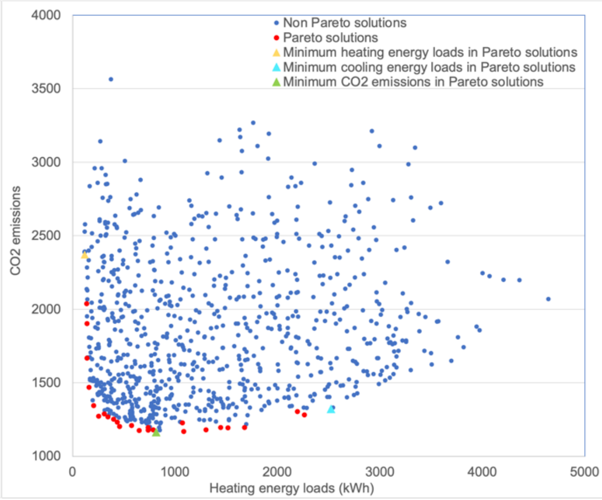
RESULTS AND DISCUSSION

In the application of the optimization, the objective function was determined by considering the annual heating energy load, the annual cooling energy load, and CO_2 emission. As mentioned before, jEPlus+EA program was used in the optimization stage and this program produces the optimum solution according to the defined objective function. In this study, a solution set in which the optimum heating energy load, cooling energy load, and CO_2 emission results of the building are minimized is obtained from the optimization program. After 92 iterations, the optimization results have reached 27 Pareto optimal solutions. To better understand the relationship between every two objectives, the optimal results for the configuration of input parameters are shown as graphically, in Table 4.

The red points represent the Pareto front of non-dominated solutions. The blue points represent the non-Pareto solutions within the design space. Also, the points representing minimum heating energy load, minimum cooling energy load, and minimum CO_2 emissions in Pareto solutions are highlighted.

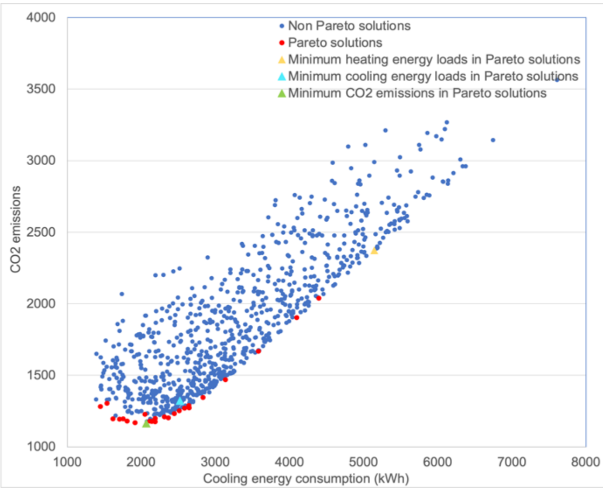
Table 4. *Optimization results*





(a) Heating and cooling energy loads optimization results

(b) Heating energy loads and CO_2 emissions optimization results



(c) Cooling energy loads and CO_2 emissions optimization results

Parameters and their values from P1-P36 and 27 solutions of three objective functions in the Pareto front are listed as the best optimal solutions in Table 5. P1-P7 and P16-P36 are the same parameters defined in the sensitivity analysis stage and C1-C4 are the window components which were P8-10 as solar heat gain coefficient and P11-15 as total heat transfer coefficient parameters in the sensitivity analysis stage. Since these two parameters were the most effective ones on heating and cooling energy loads, in the optimization stage 10 window component alternatives were determined and used for C1 on the north façade, C2 on the south facade, C3 on the east façade, and C4 on the west facade. It can be seen some of the most recommended values for optimum solutions in the four facades are different. While the most recommended component type for the north facade window is component 7 with 17 solutions of 27 Pareto front solutions; component 3 with 15 solutions on the south façade window, component 5 with 14 solutions on the east façade window and component 4 with 9 solutions and component 3 with 8 solutions on the west façade window. As mentioned in the previous sections, the window transparency rate is considered to be 80% on the north façade. While the window transparency rate is 80% on the north façade, window width and height solutions on other façades gain importance in reducing energy loads. While the most recommended window width for the south facade window is 4.5m with 11 solutions of 27 Pareto front solutions; 1.5m window width has 24 solutions on the east façade window and 1.5m window width has 19 solutions on the west façade window. While the most recommended window height for the south facade window is 2.1m has 13 solutions of 27 Pareto front solutions; 2.1m window height has 15 solutions on the east façade window, and 1.5m window height has 21 solutions on the west façade window.

Table 5. *Parameter values and heating and cooling energy loads and CO_2 emissions of the optimization results*

	P1_P2_P3_P4_P5_P6_P7_C1_C2_C3_C4_P16_P17_P18_P19_P20_P21_P22_P23_P24_P25_P26_P27_P28_P29_P30_P31_P32_P33_P34_P35_P36	Heating	Cooling	CO_2
1	0_4.5_1.5_1.5_2_2.1_1.5_7_3_6_3_0.05_0.03_0.06_0.03_800_1000_1200_1400_0.034_0.035_0.036_0.034_0.14_0.14_0.1_0.18_20_10_10_20_0.1	787.87	2115.05	1179.24
2	0_6.5_1.5_2.5_2.2_2.1_1.7_6_2_4_5_0.06_0.05_0.07_0.06_800_1200_1200_1200_0.033_0.04_0.031_0.03_0.18_0.16_0.1_0.1_20_10_70_10_0.1	142.22	3579.86	1667.99
3	0_6.5_3.5_5.5_2.1_2.2_2.1_6_5_6_6_0.06_0.05_0.08_0.08_1000_1400_1400_1400_0.033_0.035_0.034_0.037_0.1_0.16_0.1_0.14_40_10_20_30_0.1	137.58	4395.77	2037.95
4	0_4.5_1.5_1.5_2_2.1_1.5_7_3_5_5_0.05_0.03_0.07_0.06_1200_1400_1200_1200_0.034_0.035_0.035_0.035_0.12_0.12_0.1_0.18_10_10_20_70_0.9	2520.84	1380.7	1322.19
5	0_5.5_1.5_1.5_2.1_2.1_1.5_7_3_5_4_0.05_0.02_0.06_0.04_1000_1200_1000_1200_0.034_0.034_0.035_0.034_0.12_0.12_0.1_0.16_10_10_10_40_0.6	1676.64	1614.34	1196.09
6	0_4.5_1.5_1.5_2_2.1_1.5_7_3_5_5_0.05_0.03_0.07_0.06_1200_1400_1200_1200_0.034_0.034_0.035_0.034_0.14_0.14_0.12_0.16_20_10_10_30_0.5	1515.76	1706.04	1193.53
7	0_5.5_1.5_1.5_2.1_2.1_1.5_7_3_5_3_0.05_0.02_0.06_0.03_800_1000_1000_1400_0.034_0.034_0.035_0.034_0.14_0.14_0.1_0.16_20_10_10_20_0.3	1083.23	1913.23	1168.73
8	0_4.5_1.5_2.5_2.2_1.9_1.5_7_3_5_5_0.05_0.02_0.06_0.05_1200_1400_1000_1600_0.034_0.033_0.035_0.035_0.18_0.18_0.14_0.14_40_10_10_30_0.3	1073.17	2046.53	1226.61
9	0_4.5_1.5_1.5_1.7_1.9_1.5_8_1_7_4_0.07_0.06_0.06_0.06_1000_1000_1200_800_0.032_0.032_0.032_0.032_0.16_0.14_0.1_0.12_20_10_40_10_0.1	459.83	2365.59	1202.93
10	0_4.5_1.5_1.5_2_2.1_1.5_7_2_5_3_0.05_0.03_0.06_0.03_800_1000_1000_1200_0.034_0.034_0.035_0.034_0.14_0.14_0.1_0.16_20_10_10_20_0.1	574.55	2309.7	1209.08
11	0_5.5_1.5_1.5_2.1_2.1_1.5_7_3_5_3_0.05_0.02_0.06_0.03_800_1000_1000_1400_0.034_0.034_0.035_0.034_0.14_0.14_0.1_0.16_20_10_10_20_0.4	1300.66	1808.03	1180.72
12	0_6.5_2.5_5.5_2.1_2.2_2_6_4_6_6_0.06_0.04_0.08_0.08_1000_1400_1400_1400_0.033_0.035_0.034_0.037_0.1_0.16_0.1_0.14_40_10_20_30_0.1	140.06	4096.29	1902.37
13	0_6.5_1.5_2.5_1.9_1.7_1.5_9_1_10_4_0.07_0.09_0.06_0.06_1000_1000_1200_600_0.032_0.031_0.032_0.032_0.16_0.16_0.12_0.12_30_10_60_20_0.2	344.33	2581.46	1269.36
14	0_5.5_1.5_1.5_2.1_2.1_1.5_10_B_10_4_0.09_0.1_0.06_0.08_1000_800_1600_600_0.03_0.03_0.03_0.03_0.2_0.16_0.12_0.1_20_10_80_10_0.1	158.72	3133.01	1469.21
15	0_5.5_1.5_1.5_2.1_2.1_1.5_7_2_5_3_0.05_0.03_0.06_0.03_800_1000_1000_1200_0.034_0.034_0.035_0.034_0.14_0.14_0.1_0.16_20_10_10_20_0.1	437.32	2443.88	1232.36
16	0_6.5_6.5_5.5_2.1_2.2_1.5_6_10_6_6_0.06_0.09_0.08_0.08_1000_1400_2000_1400_0.033_0.04_0.034_0.031_0.16_0.14_0.1_0.14_20_10_40_10_0.1	117.08	5143.01	2372.30
17	0_5.5_1.5_1.5_2_1.9_1.5_9_B_10_4_0.08_0.09_0.06_0.07_1000_800_1400_600_0.031_0.03_0.031_0.03_0.18_0.14_0.1_0.12_20_10_60_10_0.1	207.05	2829.34	1344.35
18	0_6.5_1.5_2.5_1.9_1.7_1.5_9_1_10_4_0.07_0.09_0.06_0.06_1000_1000_1200_600_0.032_0.031_0.032_0.031_0.16_0.14_0.1_0.14_20_10_40_10_0.1	254.3	2643.36	1272.74
19	0_8.5_1.5_1.5_2.1_1.5_1.5_7_3_B_9_0.05_0.07_0.06_0.08_1600_1800_1800_2000_0.034_0.035_0.03_0.034_0.18_0.14_0.1_0.1_70_10_10_20_0.1	310.16	2642.36	1287.66
20	0_4.5_1.5_1.5_2.1_2_1.5_7_3_5_3_0.05_0.02_0.06_0.03_800_1000_1000_1200_0.034_0.035_0.035_0.034_0.12_0.14_0.1_0.16_20_10_10_20_0.1	815.58	2067.74	1165.35
21	0_5.5_1.5_1.5_2.1_2.1_1.5_7_3_5_4_0.05_0.02_0.06_0.04_1000_1200_1000_1400_0.034_0.034_0.035_0.034_0.14_0.14_0.12_0.16_20_10_10_30_0.5	1444.47	1756.57	1196.89
22	0_4.5_1.5_1.5_2_2.1_1.6_7_3_5_5_0.05_0.03_0.07_0.06_1200_1400_1200_1200_0.034_0.034_0.035_0.035_0.12_0.12_0.1_0.18_10_10_20_60_0.8	2261.02	1447.96	1281.27
23	0_5.5_1.5_2.5_2.2_2.1_1.6_7_3_5_5_0.05_0.03_0.07_0.06_1200_1400_1200_1200_0.034_0.035_0.035_0.035_0.12_0.12_0.1_0.18_10_10_20_70_0.9	2194.16	1538.07	1303.86
24	0_5.5_1.5_1.5_2.1_2.1_1.5_7_3_6_3_0.05_0.03_0.06_0.03_800_1000_1200_1400_0.034_0.035_0.036_0.034_0.14_0.14_0.1_0.18_20_10_10_20_0.1	651.65	2188.12	1174.99
25	0_4.5_1.5_1.5_2.1_2_1.5_7_3_5_4_0.05_0.02_0.06_0.04_1000_1200_2000_1400_0.033_0.04_0.034_0.031_0.16_0.14_0.1_0.14_20_10_40_10_0.1	737.98	2142.19	1177.86
26	0_4.5_1.5_1.5_2.3_1.8_1.5_8_1_3_3_0.07_0.06_0.05_0.05_800_1000_1400_1600_0.032_0.037_0.033_0.032_0.16_0.14_0.1_0.14_20_10_40_10_0.1	401.36	2511.34	1253.15
27	0_4.5_1.5_1.5_2_2.1_1.6_7_3_5_4_0.05_0.03_0.06_0.04_1000_1200_1000_1200_0.034_0.035_0.035_0.035_0.12_0.14_0.1_0.16_30_10_10_20_0.1	736.53	2185.38	1197.11

As it can be seen from the results recommended values for;

- the north window with 80% constant transparency ratio, with 0.44 SHGC value and 1.6 U value,
- the south window width is 4.5m and the height 2.1m, with 0.55 SHGC value and 1.6 U value,
- the east window width is 1.5m and the height 2.1m, with 0.48 SHGC value and 0.9 U value,
- the west window width is 1.5m and the height 1.5m, with 0.55 SHGC value and 1.1 U value.

CONCLUSION

In the study, to develop a method that can reduce the energy losses of buildings that do not have optimum orientation, a model with an 80% transparent north facade was studied in Samsun, which is located in the temperate humid climate zone in Turkey. The purpose of the application of this model in Samsun is to evaluate the buildings with wide façade openings to the north since the sea view is located in the north, as in many settlements in the Black Sea Region. Since Samsun province grew from the center to the east in a short time, the buildings were produced quickly. The heat losses due to the northward orientation in the buildings that are produced without considering the energy efficiency, reach serious amounts considering the number of buildings produced.

To reduce the heat losses from the northern façade and to produce solutions with minimum energy outputs, a method consisting of generating the building energy model, application of the sensitivity analysis and optimization has been applied. After generating the building energy model, the regression-based sensitivity analysis has been performed. Input parameters defined in the second stage and the value ranges of the parameters have been determined. These parameters are listed according to the effect on the heating and cooling energy load. At the application of the optimization stage, multi-objective optimization is performed with objective functions to be minimized are heating energy loads, cooling energy loads, and CO_2 emissions. At this stage, 10 window component alternatives have been determined, as it was concluded that the parameters related to the window had a greater effect on the heating and cooling energy loads. These alternatives are obtained by changing the solar heat gain coefficient value and the window U value. jEPlus+EA which use NSGA-II algorithm was selected as an optimization tool to produce the optimal solution set with low computational time. It has been seen that this method can be used as a decision-support approach in the process of generating solutions for non-optimal design parameters in the climatic design. Considering the amount of heat to be lost by many buildings at the city scale, it can be predicted that the heat losses to be prevented by this method are at a substantial level for the climate. Future climate scenarios and cost calculations can be included in this method in future studies.

REFERENCES

Altensis. Design Builder Software. https://www.altensis.com/hizmetler/designbuilder-software/ Accessed on August 19, 2021.

Asadi, E., Silva, MGd., Antunes, CH., Dias, L. and Glicksman, L. Multi-objective optimization for building retrofit: a model using genetic algorithm and artificial neural network and an application. Energy Build 2014; 81: 444–456

Attia, S., Hamdy, M., O'Brien, W., Carlucci, S. 2013. Assessing gaps and needs for integrating building performance optimization tools in net zero energy buildings design. Energy Build 2013;60:110–24.

Berköz, E., Küçükdoğu, M., Yılmaz, Z., Kocaaslan, G., Yıldız, E., Köknel, A., Unver, R., Ak, F., Enarun, D. ve Yıldız, D. 1995. Energy efficient housing and settlement design. The Scientific and Technological Research Council of Turkey (Project No: Tübitak-Intag 201).

Crawley, D., A., Lawrie, L. 2021. Climate Files. climate.onebuilding.org. Accessed October 01, 2021.

Coello, C. 2006. Evolutionary multiobjective optimisation: a historical view of the field, IEEE Computational Intelligence Magazine 1 (1) (2006) 28–36.

Deb, K., Pratap, A., Agarwal, S., Meyarivan, T. 2002. A fast and elitist multiobjective genetic algorithm: NSGA-II. IEEE T Evolut Comput. 6 (2), 182–197.

Energy Plus, https://energyplus.net/weather-location/europe_wmo_region_6/TUR//TUR_Izmir.172180_ IWEC. Accessed December 15, 2021.

Gerçek, M., Arsan, Z.D. 2019. Energy and environmental performance-based decision support process for early design stages of residential buildings under climate change, Sustainable Cities and Society, 48, 101580.

Jing Zhao, J., Du, Y. 2020. Multi-objective optimization design for windows and shading configuration considering energy consumption and thermal comfort: A case study for office building in different climatic regions of China. Solar Energy 206 (2020) 997–1017.

Lei, Y.J., Zhang, S.W., Li, X.B., Zhou, C.M. 2005. MATLAB genetic algorithm toolbox and application. Xidian University Press.

Li T., Shao G., Zuo W., Huang S. 2017. Genetic algorithm for building optimization: state-of-the-art survey. In: Proceedings of the 9th international conference on machine learning and computing. p. 205–10.

Naji, S., Aye, L., Noguchi, M. 2021. Multi-objective optimisations of envelope components for a prefabricated house in six climate zones. Applied Energy. 282 (2021) 116012

Nguyen, A. T. 2013. Sustainable housing in Vietnam: climate responsive design strategies to optimize thermal comfort. PhD Thesis, Liege University, Liege, Belgium.

Nguyen, A.T., Reiter, S., Rigo, P. 2014. A review on simulation-based optimization methods applied to building performance analysis. Applied Energy, 113 (2014) 1043–1058.

Roulet CA, Flourentzou F, Labben HH, Santamouris M, Koronaki I, Dascalaki E and Richalet V. 2002 ORME: a multicriteria rating methodology for buildings. Build Environ 2002; 37: 579–586.

Saltelli, A., Tarantola, F., Campolongo, F., Ratto, M. 2004. Sensitivity Analysis in Practice: A Guide to Assessing Scientific Models, John Wiley & Sons Ltd., England.

Şenel Solmaz, A. 2015. A decision support model based on simulation and multi-objective optimization to determine optimum solutions for building energy performance. PhD Thesis, Dokuz Eylül University, İzmir, Turkey.

Şenel Solmaz, A., Halicioğlu, F. H., Gunhan, S., 2016. An approach for making optimal decisions in building energy efficiency retrofit projects. Indoor and Built Environment. Vol. 27 (3) 348-368.

Tavares, P. F. A. F., Martins, A. M. O. G. 2007. Energy efficient building design using sensitivity analysis. A case study. Energy and Buildings, 39(1), 23–31.

T.R. Ministry of Agriculture and Forestry, General Directorate of Meteorology. General Statistics of Our Provinces. https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler istatistik.aspx?k=undefined&m=SAMSUN. Accessed August 10, 2021.

Tian, W. 2012. A review of sensitivity analysis methods in building energy analysis. Renewable and Sustainable Energy Reviews. Vol. 20, pp. 411-419.

Turkish Standards Institution (TSE). 2008. TS 825 - The Thermal Insulation Requirements for Buildings (revision) in Turkish Context. Ankara, Turkey.

Turkish Statistical Institute (TurkStat). 2019. Indicator Application. https://biruni.tuik.gov.tr/ilgosterge/?locale=tr. Accessed October 05, 2019.

Turkish Statistical Institute (TurkStat). 2021. Family with Statistics 2021. https://data.tuik.gov.tr Accessed October 11, 2022.

T.C. Official Gazette. 2010. Binalarda Enerji Performansı Ulusal Hesaplama Yöntemine Dair Tebliğ (No: YİG/2010-02), 27778. https://www.resmigazete.gov.tr/ eskiler/2010/12/20101207M1-1.htm

Ulukavak Harputlugil, G., Enerji Performansı Öncelikli Mimari Tasarım Sürecinin İlk Aşamasında Kullanılabilecek Tasarıma Destek Değerlendirme Modeli, Doktora Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara, 2009.

Uzuneminoğlu, H. 1992. An Applied Urban Geography, PhD Thesis, İstanbul University, İstanbul, Turkey.

Zhang, Y., Korolija, I. 2010. Performing complex parametric simulations with jEPlus, SET2010-9th International Conference on Sustainable Energy Technologies, Shangai-China, 24-27 August 2010.

Zhang Y., Jankovic L. 2017. JEA, An Interactive Optimization Engine for Building Energy Performance Simulation, IBPSA Building Simulation 2017, San Francisco-USA, 7-9 Ağustos, 2017.

Yıldız, Y., Korkmaz, K., Göksal Özbalta, T., Durmuş Arsan, Z. 2012. An approach for developing sensitive design parameter guidelines to reduce the energy requirements of low-rise apartment buildings. Applied Energy, 93, 337–347.

Yılmaz, A. 2004. New development areas of Samsun city. Turkish Journal of Geography, Vol. 42, pp. 59-72, İstanbul, Turkey.

Yılmaz, C. 2011. Samsun City, Location and Urban Development Features, Samsun Symposium 2011, Samsun, Turkey.