

TECHNICAL ARTICLE

# Energy Performance Optimization of School Buildings in Different Climates of Turkey

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Today, the building sector has a large share in global energy consumption. The building stock, which has increased with the increasing population, contributes more to this consumption day by day. School buildings, which constitute an important part of public buildings, are among the most used building types in the daily cycle and also have a high energy demand for heating, cooling and electricity loads. In Turkey, the implementation of the same type of school projects in different climate regions without considering the context and climatic conditions increases the amount of energy consumption. This study provides a framework for reducing energy loads in school buildings using passive design strategies. Located in two different climatic regions of Turkey, in Istanbul and Ankara, a primary school building is taken into consideration for comparison of type projects in the context of energy performance and single-objective optimization process to minimize energy use intensity (EUI). As a result of the optimization processes carried out depending on the parameters related to the building envelope, the energy performance for the Istanbul climate is improved by 5.05%, while this rate is 4.09% for the Ankara climate. The best solution individual parameters of both climate types have very close values to each other. It is thought that more efficient results can be obtained with the multi-objective optimization processes of the studies to be carried out to evaluate the type school projects on the basis of different climates.

**Keywords:** energy performance; performance simulation; optimization; school buildings; energy conservation

## Introduction

Today with the rapid population growth, due to the changing needs and consumption habits, irreversible damages are given to the nature. The need for ever-increasing energy, especially in cities, does not help to reduce the consequences, such as global warming, but is adversely affecting each year. When the energy consumption in the world is examined, it is seen that building construction and operations have the biggest share in this consumption with a rate of 36%. Research shows that the energy demand of buildings increased by 7% from 2010 to 2018 (IEA, 2019). For all these reasons, the building sector is seeking alternative designs in order to consume less energy and to gain maximum benefit from sustainable resources. It is aimed to contribute to the solution of problems with energy-efficient and performance-based designs that reduce the energy consumed by buildings throughout their life cycle and cause minimum damage to the environment and human health.

In order to achieve these goals, generally, many decisions need to be made in the early design stage of buildings, in the multi-disciplinary field, on various issues such as energy performance, cost, environmental impact. With the advancing digital technologies, designers have the opportunity to integrate technical and performance criteria into design at the early stages of design thinking and to test design effects algorithmically and/or iteratively (Goldman and Zarzycki, 2014: 4). Especially in recent years, significant progress has been made in this area with the combination of parametric design tools and optimization methods. These tools work in conjunction with various simulation engines and make it possible to evaluate design alternatives by providing performance measurements for buildings. Thus, parametric models can respond very effectively to performance-based design decisions. In addition, the integration of parametric modeling and optimization methods based on algorithms enables the production of better solutions by investigating a more systematic solution range (Turrin, von Buelow, Kilian and Stouffs, 2011). Optimization studies are generally carried out in the early design stage, where most of the design decisions are made (Negendahl and Nielsen, 2015) and can be performed as single-objective or multi-objective in the context of the number of objective functions (Attia,

Hamdy, O'Brien and Carlucci, 2013). Evins (2013) stated in his literature review study focusing on the use of computational optimization methods in sustainable building design, 53% of the studies used single-objective optimization and 39% used multi-objective optimization.

In recent years, it is seen that there are many building performance optimization studies based on parameters and algorithms in the relevant literature. For example, a multi-objective optimization has been carried out with using the parameters of the number, location, shape and type of windows and wall thickness to reduce the energy used for heating, cooling and lighting on an open-plan office building in the cities of Palermo, Turin, Frankfurt and Oslo, which has four different climate types (Echenagucia, Capozzoli, Cascone and Sassone, 2015). Single-objective optimization and energy simulations were used to increase thermal comfort in the study on overhangs of a two-storey type building located in three different cities of Morocco. Comparing the optimized design with the base case, it was observed that there was a decrease in cooling loads between 2.7% and 4.1% in different cities, while an increase in heating loads between 2.8% and 1.9% (Sghouri, Mezrhab, Karkri, and Naji, 2018). Konis, Gamas, and Kensek (2016), in their multi-purpose optimization study on the ASHRAE 90.1 compliant reference building, reduced the energy use intensity between 4% and 17% while improved the daylight performance between 27% and 65% depending on the different region and climatic conditions.

When the building stock in the world is examined, it is seen that school buildings, which constitute an important part of public buildings, are among the most used building types in the daily cycle and also have a high energy demand for heating, cooling and electricity loads. When the researches on schools are examined, it is seen that optimization studies have been conducted in various areas such as cost, energy, thermal comfort, and daylight. For example; in the simulation-based multi-objective optimization study conducted to investigate cost-optimal renovation options in cold climatic regions, options were evaluated over various renewable energy production systems and it was determined that PV-panels showed the best improvement in energy performance (Niemelä, Kosonen, and Jokisalo, 2016). In another study, to assess the cost-optimal energy efficient retrofit options, a case study, on a school project in Turkey, conducted by using a multi-objective optimization to find optimal solution range between heating and cooling savings and net present value (Şenel Solmaz, Halicioğlu, and Gunhan, 2018). On a passive school building in Southern Germany, a study was carried out both in the single classroom and the whole school building, evaluating different indoor set-point temperatures, shading system, pre-ventilation and the efficiency of heat recovery facility (Wang, et al., 2015). Futrell, Ozelkan and Brentup (2015) used eleven different design parameters in their optimization study on a single-zone classroom in Charlotte, NC to maximize daylight and thermal comfort.

Various parameters such as different plan typologies, orientation, width, window to wall ratio, glazing materials, shading types were used in the optimization study to minimize energy use, reduce summer discomfort and maximize useful daylight illumination (UDI<sub>avg</sub>) in the cold climate region of China. As a result of the optimization study, energy demand has been reduced up to 28%, summer thermal discomfort has been reduced up to 23%, and the UDI<sub>avg</sub> value has been increased up to 63% with different solutions (Zhang, et al., 2017). Bakmohammadi and Noorzai (2020), on the other hand, evaluated a class to find optimized solutions in terms of energy performance and thermal comfort, and in the next phase of the study, a second evaluation was made for the visual comfort of the users through optimum designs. In their study, Zomorodian and Nasrollahi (2013) achieved a 31% reduction in energy demand by preserving visual and thermal comfort compared to the base case, in their optimization study by evaluating different architectural design parameters on a school project in Iran.

When looking at general, it is seen that energy efficiency of buildings can be increased with both active strategies like HVAC systems and passive strategies (Sadineni, Madala and Boehm, 2011). In particular, passive solar design strategies have a significant impact on building performance. Because natural weather conditions have a great impact on building performance and passive strategies evolve depending on these conditions. By controlling the parameters such as form, orientation and building envelope elements, which form the basis of passive strategies of the design, performance effects can be increased to higher levels (Stevanović, 2013). Especially, energy consumption rates in buildings are strongly dependent on the properties of the building envelope that separates indoor and outdoor environments (Schiavoni, Bianchi and Asdrubali, 2016).

From this respect, this study aims to provide a framework for reducing energy loads in school buildings using passive design strategies. Paper focuses on the energy performance in school buildings, which are used extensively in the daily cycle and contribute to energy consumption in the context of heating, cooling and electrical loads. According to Republic of Turkey Ministry of National Education (MoNE) (2020), in Turkey, there are 57,104 school buildings for 16,612,161 students from primary education level to higher education level. When considering the public-school projects implemented in Turkey, it is observed that the type projects implemented throughout the country ignoring the context and different climate conditions. This causes an increase in energy consumption. This paper presents a simulation-based "single-objective" optimization process to evaluate type school projects in Turkey in the context of energy performance with various passive strategies associated with the building envelope, such as window-to-wall ratios, wall and glazing materials, insulation thickness. A selected type primary school project is examined both in İstanbul and Ankara located in different climate zones of Turkey to reduce energy use intensity.

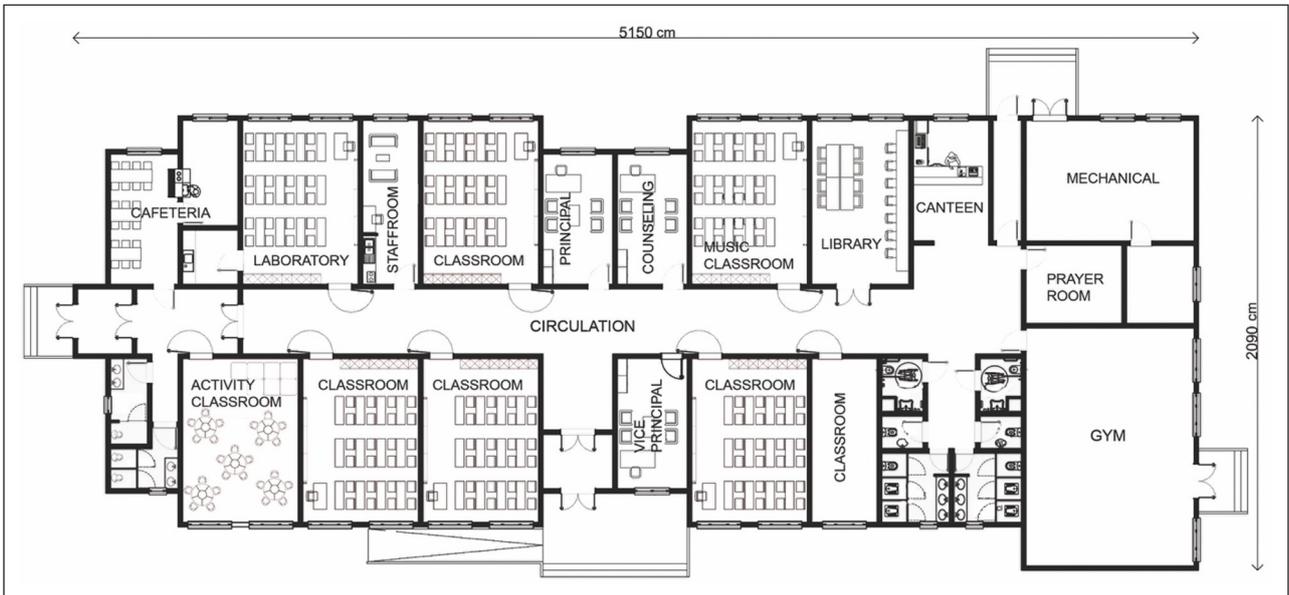
**Material and Method**

In this part of the study, the simulation-based process carried out for single-objective optimization related with the energy consumption on the determined school building is explained. First of all, the type projects of educational buildings in 2020 shared by the Republic of Turkey Ministry of National Education (MoNE, 2020a) are examined and the concept project of a primary school building is selected to be used in the case study. The selected primary school building, as can be seen in **Figure 1**, is a single-storey, rectangular shaped building and consists of various units such as classrooms, cafeteria, staffroom, laboratory, gym, restrooms, library, prayer room.

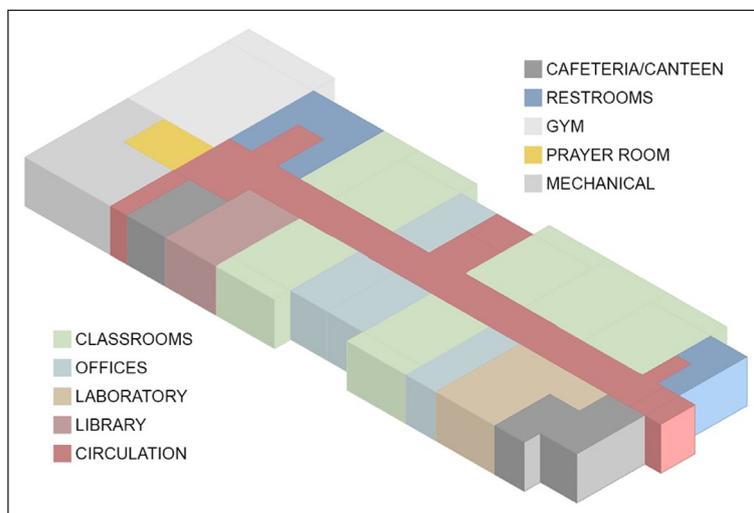
After the selecting the project, the digital model for energy simulation has been prepared to evaluate the energy performance of the building. The building model is created in the Rhino program and is defined on the Grasshopper software. Then, an energy model is set

up with the Honeybee plug-in in order to evaluate the energy performance of the building in different climates of Turkey. While creating the energy model, firstly the thermal zones which have different loads of the building are defined on the Honeybee plug-in. As can be seen in **Figure 2**, the building has been evaluated over ten different thermal zones as classrooms, offices, laboratory, library, circulation, cafeteria/canteen, toilet, gym, prayer room, mechanical.

After the thermal zones are created, the zone programs are determined and the equipment loads, lighting loads and number of people per area are defined separately on each zone. Once the zone loads are determined, occupancy, lighting, equipment, heating and cooling schedules belonging to the zones are created and added as an input to the simulation model. It is assumed that education at the school takes place between 08.00–16.00 hours and the time period between 12.00–13.00 hours is thought as



**Figure 1:** Floor plan of the selected primary school building (MoNE, 2020a).



**Figure 2:** Thermal zones of the energy model.

lunch break. In general, since the lighting and equipment loads are determined according to the occupancy situation, the factors in the daily cycle are kept equal while preparing the occupancy, lighting and equipment schedules.

However, three different schedule scenarios are created depending on the general usage of building units. It is assumed that the heating and cooling systems in the school building are operated between 07.00 and 17.00 hours, and it has been assumed that no cooling system is used in the restrooms, circulation and mechanical thermal zones. The heating set point is set to 22 °C throughout

the school, while the cooling set point is set to 26 °C. On weekends, it is assumed that the building is not used, and the heating and cooling systems are not operated. Loads in zones and schedule scenarios are shown in **Tables 1** and **2** in detail.

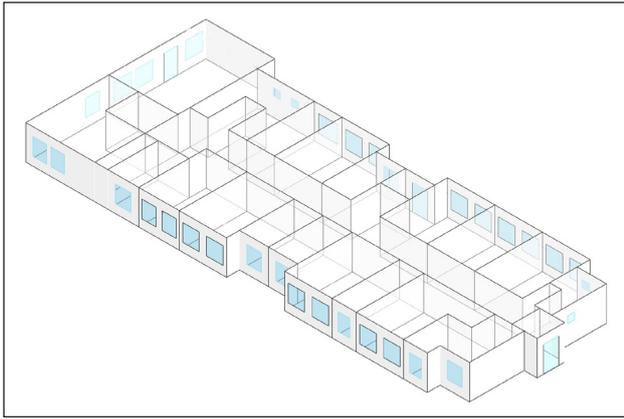
After the data of zone loads and schedules are entered into the energy model, the adjacent surfaces between the zones are defined and then the transparent surfaces on the building envelope are added to the model (**Figure 3**), and the model is brought into a state where the materials could be defined.

**Table 1:** Zone loads of energy model.

Thermal Zones	Area (m <sup>2</sup> )	Equipment Load Per Area (W/m <sup>2</sup> )	Lighting Density Per Area (W/m <sup>2</sup> )	Num Of People Per Area (ppl/m <sup>2</sup> )
Classrooms	284.60	8.5	10.5	0.62
Offices	86.30	7.86	10	0.05
Laboratory	50.60	12	10.5	0.5
Gym	90.00	3.66	10	0.3
Library	36.90	8.5	10.5	0.23
Cafeteria/Canteen	56.80	12	10	0.72
Circulation	194.40	2.9	4.5	0.1
Prayer Room	17.50	2.9	4.5	0.1
Restrooms	58.60	2.9	8	0.1
Mechanical	59.70	2.9	10	0.01

**Table 2:** Zone schedules.

Thermal Zones	Occupancy/Lighting/Equipment Schedules
General	weekdays 07.00–08.00 = 0.25; 12.00–13.00 = 0.75; 13.00–16.00 = 1; 16.00–17.00 = 0.1; 17.00–07.00 = 0
	weekend 00.00–23.59 = 0
Staffroom Cafeteria/Canteen Prayer Room	weekdays 07.00–12.00 = 0.15; 12.00–13.00 = 0.90; 13.00–17.00 = 0.1; 17.00–07.00 = 0
	weekend 00.00–23.59 = 0
Laboratory Gym	weekdays 10.00–12.00 = 1; 12.00–13.00 = 0; 13.00–15.00 = 1; 15.00–10.00 = 0
	weekend 00.00–23.59 = 0
<b>Heating Set Point Schedule</b>	
All Zones	weekdays 07.00–17.00 = 22 °C; 17.00–07.00 = no heating
	weekend 00.00–23.59 = no heating
<b>Cooling Set Point Schedule</b>	
All Zones (except: Circulation Restrooms Mechanical)	weekdays 07.00–17.00 = 26 °C; 17.00–07.00 = no cooling
	weekend 00.00–23.59 = no cooling



**Figure 3:** Selected type school building's base model view with transparent surfaces.

**Base Case Analysis**

In this part of the study, in order to evaluate the energy performance of the building before optimization, an energy simulation is performed by assigning materials specific to both Istanbul (41°00'N, 28°58'E) with moderate climate and Ankara (39°92'N, 32°85'E) with cold climate and completing the energy model with the necessary steps. Base case construction materials were formed utilizing the current standard TS 825 in Turkey. In standard, Turkey is evaluated through four different climate zones according to degree days and İstanbul and Ankara is located at 2<sup>nd</sup> and 3<sup>rd</sup> region respectively (TS 825, 2008). According to standard, the maximum heat transfer coefficient (U) values of the materials that should be used in the 2<sup>nd</sup> and 3<sup>rd</sup> climatic zones are shown in **Table 3**.

While preparing construction materials, the  $U_{wall}$ ,  $U_{roof}$ ,  $U_{gf}$  values in **Table 3** are used exactly for the cities, while the glazing system values in **Table 4** are used in the simulation model for both cities, since the frame value is not taken into account for the windows.

After the material values are entered separately for each city, the last steps required for the energy simulation

**Table 3:** U-value requirements according to TS825.

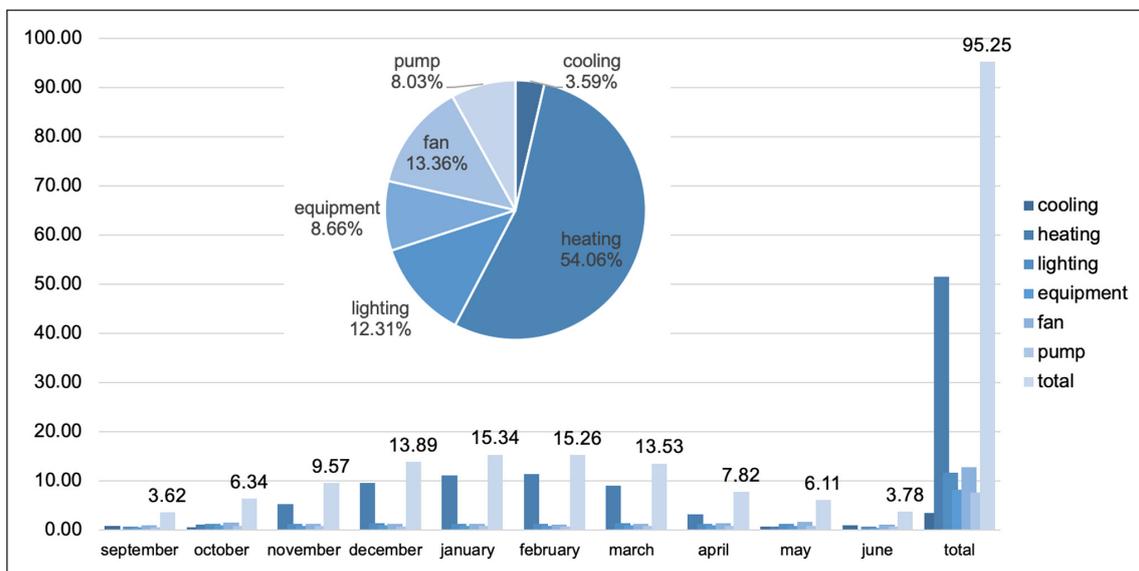
Region	$U_{Wall}$ [W/m <sup>2</sup> K]	$U_{Roof}$ [W/m <sup>2</sup> K]	$U_{GroundFloor}$ [W/m <sup>2</sup> K]	$U_{Window}$ [W/m <sup>2</sup> K]
2 <sup>nd</sup>	0.60	0.40	0.60	2.40
3 <sup>rd</sup>	0.50	0.30	0.45	2.40

**Table 4:** Glazing system properties used on base cases.

<b>Layers</b>	3 mm clear glass + 15 mm air + 3 mm clear glass
<b>Properties</b>	U-value: 2.730 (W/m <sup>2</sup> K); SHGC: 0.764; Tvis: 0.814

model have been completed. First of all, the fan coil units system is selected as the HVAC system of the building, the climate data of Istanbul and Ankara are entered for two different simulations, and as the analysis period of energy simulation, from 15 September at 01:00 to 15 June at 24:00 has been selected considering that schools are generally open between these dates. It is assumed that there are no structures around the building that affect the energy simulation or obstruct the sun, and the roof shape is not taken into account in the simulation. In addition, it is assumed that the building is located on the east-west axis for the building orientation. By selecting the monthly evaluation option for the simulation outputs, it has been ensured that the energy use intensity (EUI) values are obtained on a monthly distribution basis. After all the adjustments are completed, the simulation is provided with EnergyPlus via the Open Studio program.

Once the simulations are finished, EUI values obtained in the context of cooling, heating, lighting, equipment, fan and pump loads together with the entered parameter values are 95.25 kWh/m<sup>2</sup> and 126.22 kWh/m<sup>2</sup> respectively for Istanbul and Ankara as can be seen from the graphs in **Figures 4** and **5**.



**Figure 4:** EUI values and loads percentages of base case model for Istanbul.

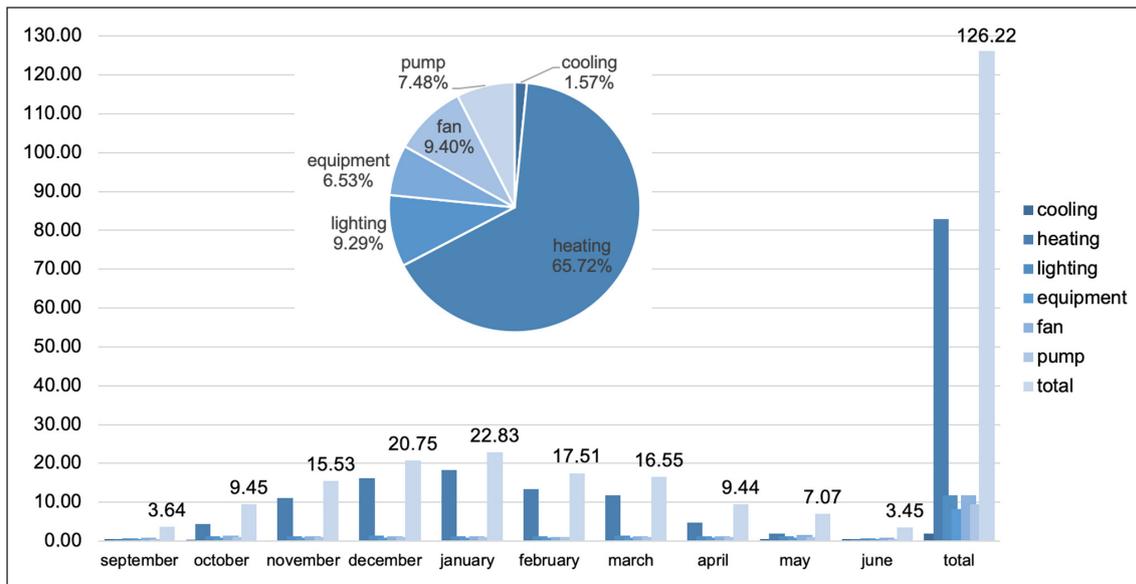


Figure 5: EUI values and loads percentages of base case model for Ankara.

Although U-values of construction materials are used lower for Istanbul than for Ankara, the EUI value for Ankara is higher. When the values are examined, it can be seen that the highest rates in both values belong to heating loads. However, the ratio of heating loads to total energy use intensity is 54.06% for Istanbul, while this rate is 65.72% for Ankara. Since Ankara is located in a colder climate zone than Istanbul, the heating load rate is higher as expected. Conversely, the cooling load rate for the Istanbul climate is higher than the Ankara climate. However, for both Istanbul and Ankara, cooling loads have the minimum percentage in proportion to total consumption. The month with the highest energy consumption is January for both climates. The month with the least energy consumption for Istanbul is September, while the month with the least energy consumption for Ankara is determined as June.

### Parametric Modeling and Optimization

After the base case simulations are completed, in this part of the study, parametric modeling and optimization stages are carried out. Firstly, the parameters and values that is used in single-objective optimization to minimize the EUI value are set. To evaluate type school projects in Turkey in the context of energy performance, some passive strategies having a direct impact on energy consumption are selected in context of building envelope. Like window-to-wall ratios (WWRs), insulation thickness, wall and glazing materials. All parameters and values used in the study can be seen in Table 5. WWRs of all thermal zones are evaluated separately, also depending on the directions. The glazing surfaces of the restrooms, mechanical, gym, circulation zones, which are not seen in the table, are kept constant with the base case and are not taken as parameters in the optimization evaluation.

Table 5: Design parameters and possible values.

Design Parameters	Possible Values	Number of Options
Classrooms WWR North	from 0.35 (base case) to 0.75 (with 0.05 increment)	9
Classrooms WWR South	from 0.35 (base case) to 0.75 (with 0.05 increment)	9
Offices WWR North	from 0.25 (base case) to 0.75 (with 0.1 increment)	6
Offices WWR South	from 0.25 (base case) to 0.75 (with 0.1 increment)	6
Cafeteria/Canteen WWR North	from 0.25 (base case) to 0.75 (with 0.1 increment)	6
Library WWR	from 0.35 (base case) to 0.75 (with 0.1 increment)	5
Laboratory WWR	from 0.35 (base case) to 0.75 (with 0.05 increment)	9
Insulation Thickness	from 0.02 m to 0.09 m (with 0.01 m increment)	8
Wall Material	Brick/Aerated Concrete	2
Glazing System	Type 0 (base case)/Type 1/Type 2/Type 3	4

Also, in the optimization process, the roof and ground floor U-values are kept the same as the base cases, both for Istanbul and Ankara, and are not included in the parameters to be joined to the optimization. The characteristics of the construction materials involved in optimization are as in **Table 6**. Note that the wall construction used in optimization is externally insulated and consists of cement plaster, insulation material (XPS), wall material and gypsum plaster from outside to inside.

After the installation of the parametric model is completed, an optimization process is initiated for both Istanbul and Ankara to minimize EUI value with the Galapagos, an evolutionary solver plug-in for Grasshopper. Galapagos settings used in the optimization process are as follows:

- Max. Stagnant: 30
- Population: 50
- Initial Boost: 3

### Results and Discussion

In this part of the study, the results of the energy performance optimization process performed in the previous section on the selected type of primary school project are discussed and the data obtained are analyzed. The optimization process carried out with the Galapagos plug-in took place at different time duration for Istanbul and Ankara, and better solutions were tried to be produced in each generation with evolutionary algorithms during the optimization process. While the optimization process in the context of Ankara ended in the 49<sup>th</sup> generation, the optimization process in the context of Istanbul continued

until the 64<sup>th</sup> generation. For both climate types, solutions for all generations can be seen in **Figures 6** and **8**.

When the optimization results for Istanbul are evaluated, it is seen that the EUI values vary between 90.44 kWh/m<sup>2</sup> and 98.52 kWh/m<sup>2</sup>. The minimum EUI value achieved over the generations is 90.44 kWh/m<sup>2</sup>. When this value is compared with the base case value, it is seen that the energy performance is improved by 5.05% with this solution individual for Istanbul climate.

When the EUI value of the best solution is examined, it is seen that the ratio of heating loads to the total energy use intensity is 54.14% (**Figure 7**). When this ratio is compared with the base case, it is seen that the ratio of heating loads increases by 0.08%. The rate of cooling loads decreased by 0.87%. Although the ratio of heating and cooling loads in general consumption has the opposite effect, the EUI values of both have decreased compared to the base case. When looking at the base case, energy consumption decreased from 3.42 kWh/m<sup>2</sup> to 2.46 kWh/m<sup>2</sup> in terms of cooling while it is decreased from 51.49 kWh/m<sup>2</sup> to 48.97 kWh/m<sup>2</sup> for heating. It is seen that fan and lighting loads cause the highest consumption after heating. When looking at the worst solution individual for Istanbul, it is seen that it generally takes high WWR parameter values and has the highest U values for both wall and glazing materials.

Looking at the optimization results for Ankara, it is seen that the EUI values vary between 121.06 kWh/m<sup>2</sup> and 131.15 kWh/m<sup>2</sup> and the energy performance of the individual with the best energy performance is increased by 4.09% when compared with the base case.

When the optimized solution is compared with the base case, it is seen that the ratio of heating loads decreases, and

**Table 6:** The characteristics of the construction materials involved in optimization process.

Material Name	Thickness (m)	Conductivity (W/mK)	Density (kg/m <sup>3</sup> )	Specific heat (J/kgK)	References
Brick	0.25	0.33	600	830	(TS 825, 2008; Wakili, et al., 2015)
Aerated Concrete	0.25	0.16	500	1000	
XPS	0.02 to 0.09	0.035	30	1500	(Şenel Solmaz, et al., 2018)
Cement Plaster	0.03	0.720	1860	800	(IES, 2018)
Gypsum Plaster	0.02	0.420	1200	837	
Glazing Types	Layers	U-value (W/m <sup>2</sup> K)	SHGC	Tvis	
Type 0	3 mm clear glass 15 mm air 3 mm clear glass	2.730	0.764	0.814	All glazing systems created via "WINDOW" software
Type 1	3 mm clear glass 15 mm argon 3 mm clear glass	2.582	0.764	0.814	
Type 2	3 mm LoE 15 mm air 3 mm clear glass	1.677	0.274	0.645	
Type 3	3 mm LoE 15 mm argon 3 mm clear glass	1.372	0.270	0.645	

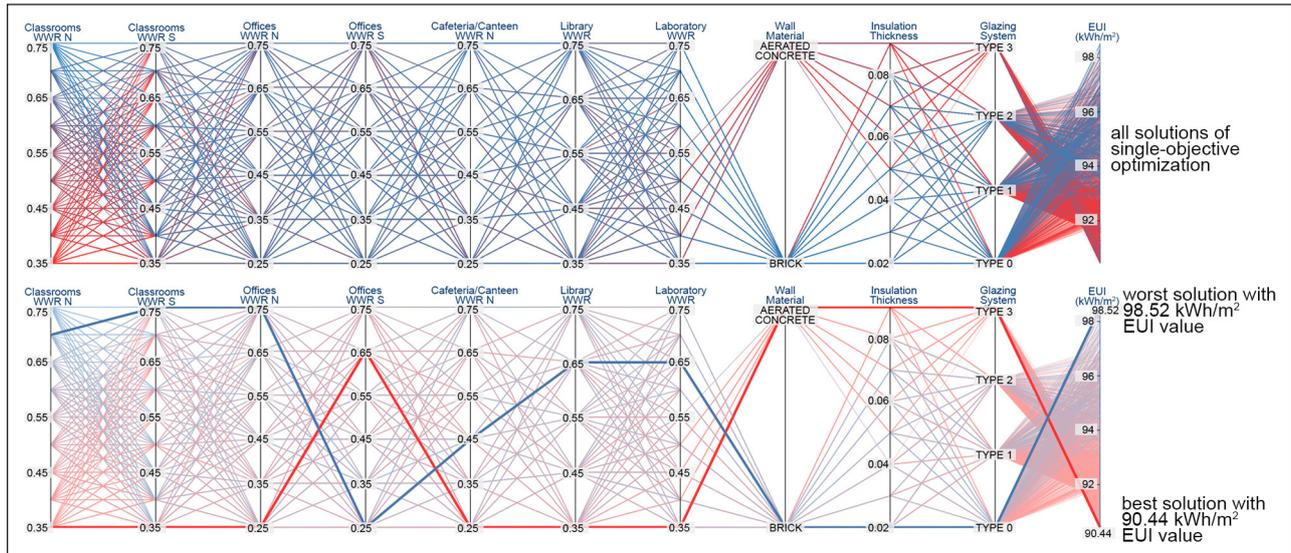


Figure 6: Optimization results for Istanbul.

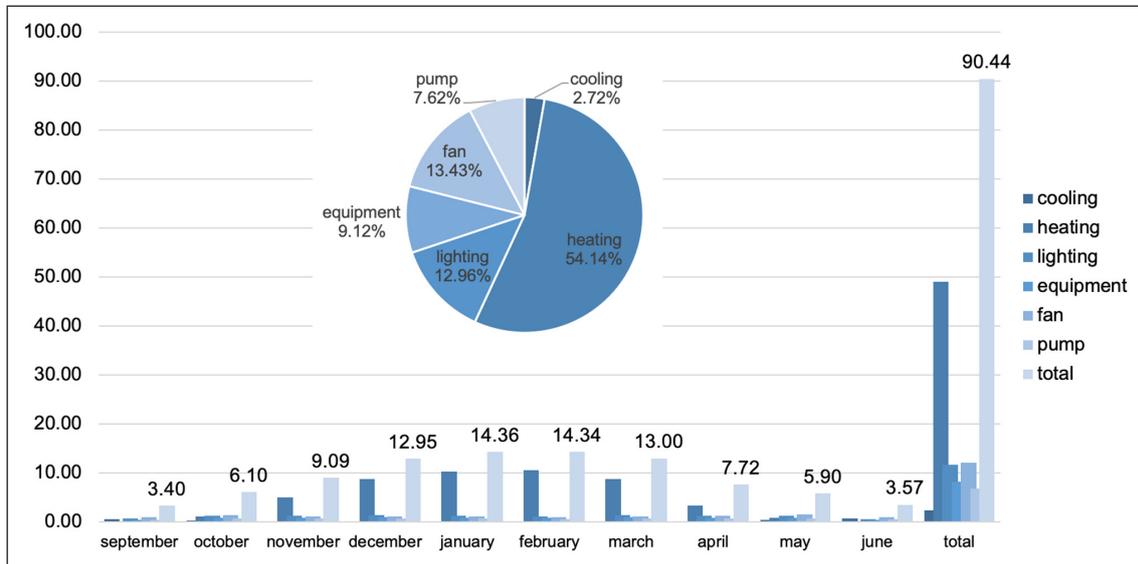


Figure 7: EUI values and loads percentages of optimized solution for Istanbul.

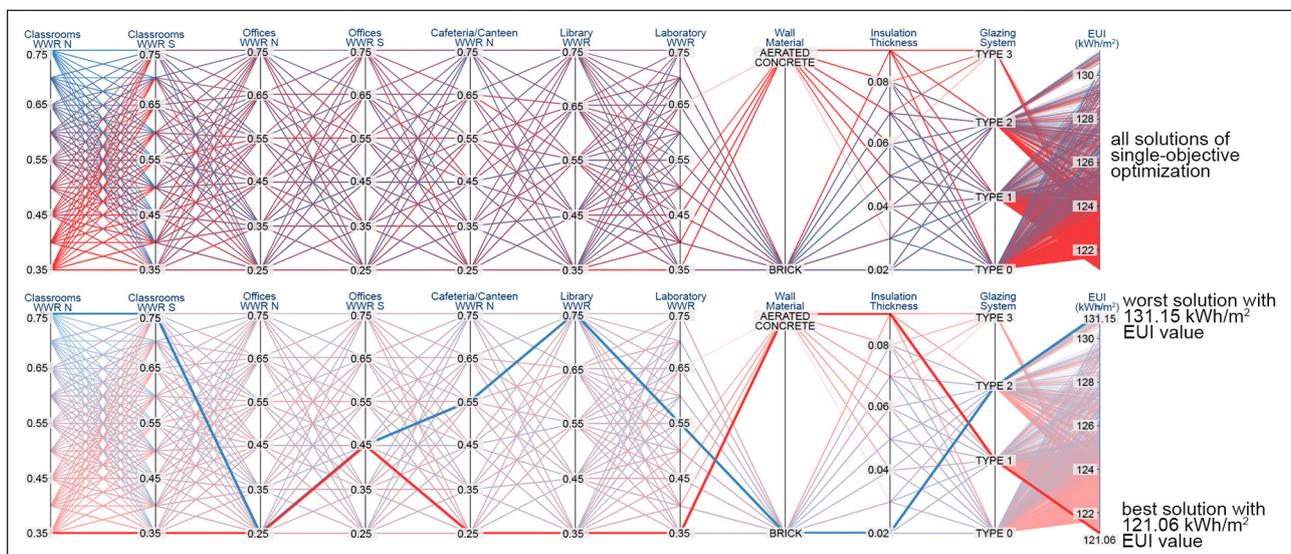
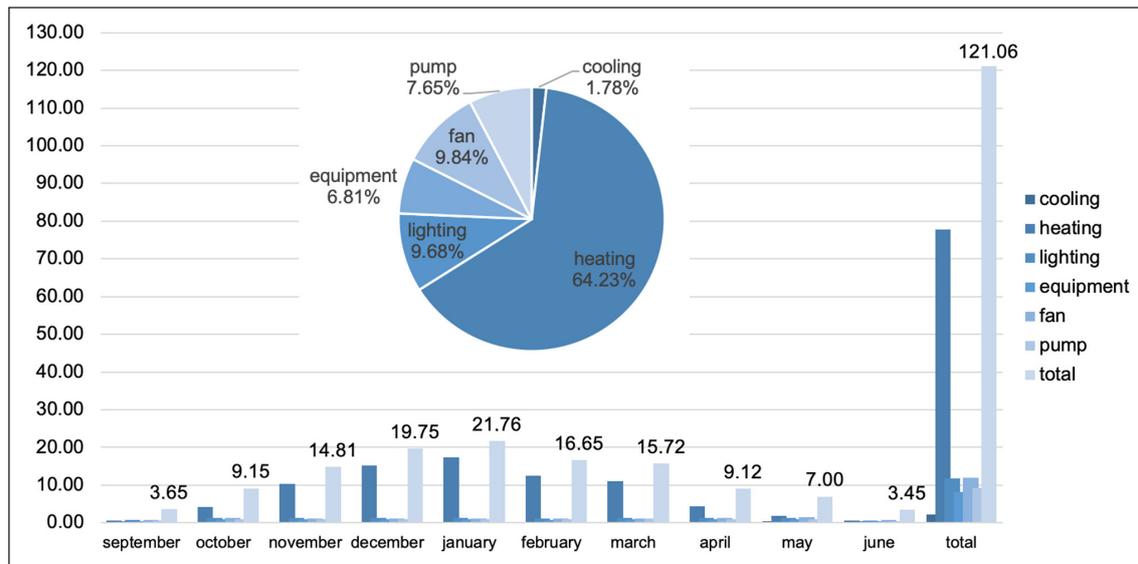


Figure 8: Optimization results for Ankara.



**Figure 9:** EUI values and loads percentages of optimized solution for Ankara.

the rate of cooling loads increases for Ankara (**Figure 9**). Considering that the opposite situation occurs for the climate of Istanbul with the optimized solution, it can be said that in fact, similar parameter values create contrast for different climate types. For Ankara cooling EUI value increased from 1.98 kWh/m<sup>2</sup> to 2.16 kWh/m<sup>2</sup> when comparing with the base case, while heating EUI value decreased from 82.96 kWh/m<sup>2</sup> to 77.75 kWh/m<sup>2</sup>. When looking at the worst solution individual for Ankara, it is seen that it generally takes high WWR parameter values and has the highest U values for wall materials.

When looking at the parameters of the best solutions for both climate types, it is seen that only the south facade WWR of the offices and the glazing type differ. In both solutions, base case values are preferred to minimize the EUI value in other WWRs except the south facade of the offices.

While glazing type 3 is preferred for the optimized solution for Istanbul, glazing type 1 is preferred for the optimized solution for Ankara. Choosing the glazing type with the lowest SHGC value for Istanbul has been effective in reducing cooling loads.

The selected wall materials and insulation thickness are the same in both optimized solutions. The selected parameter values (aerated concrete + 0.09 m insulation) together are set as the  $U_{wall}$  value of 0.24 W/m<sup>2</sup>K for both solutions. Despite the lower  $U_{wall}$  value of the wall compared to the base cases and the selection of glazing types with lower U-values compared to the base case in both solutions, a high rate of improvement in energy performance could not be achieved.

Considering the parameter values of the best solution individuals for both climate types, although the U-values for both wall and glazing have been increased, the energy performance does not show a high rate of improvement, showing that different parameters related to design should also be taken into consideration. In addition, it is thought that more efficient results will be obtained in evaluating type projects in different climates with different performance objectives, and it can be more easily

demonstrated that type projects in different climate types should have different design inputs with multi-objective optimization process.

### Conclusion

Within the scope of this study, in order to draw a framework for evaluating the energy performance of buildings that have a high share in global energy consumption, at Turkey's two different climatic zones, Istanbul and Ankara, on a type primary school concept project, a single-objective optimization process is carried out to minimize the energy use intensity. As a result of the optimization carried out separately for Istanbul and Ankara, energy performances have been improved by 5.05% and 4.09% respectively with the selected envelope parameters. However, compared to the base case, although the U-values for both wall and glazing are reduced in optimized solutions, the fact that there are no high differences in EUI values has revealed that different parameters other than the building envelope elements should be evaluated during the design process of type school projects. For future studies, it is thought that the evaluation of different performance metrics related to daylight, thermal comfort, cost, life cycle analysis *etc.* together with the multi-objective optimization process will help to make design decisions that will be effective on the type projects to be made in different climate zones.

### Competing Interests

The authors have no competing interests to declare.

### References

- Attia, S, Hamdy, M, O'Brien, W and Carlucci, S.** 2013. Assessing gaps and needs for integrating building performance optimization tools in net zero energy buildings design. *Energy and Buildings*, 60: 110–124. DOI: <https://doi.org/10.1016/j.enbuild.2013.01.016>
- Bakmohammadi, P and Noorzai, E.** 2020. Optimization of the design of the primary school classrooms in terms of energy and daylight performance

considering occupants' thermal and visual comfort. *Energy Reports*, 6: 1590–1607. DOI: <https://doi.org/10.1016/j.egy.2020.06.008>

- Echenagucia, TM, Capozzoli, A, Cascone, Y and Sassone, M.** 2015. The early design stage of a building envelope: Multi-objective search through heating, cooling and lighting energy performance analysis. *Applied energy*, 154: 577–591. DOI: <https://doi.org/10.1016/j.apenergy.2015.04.090>
- Evins, R.** 2013. A Review of Computational Optimisation Methods Applied to Sustainable Building Design. *Renewable Sustainable Energy Reviews*, 22: 230–245. DOI: <https://doi.org/10.1016/j.rser.2013.02.004>
- Futrell, BJ, Ozelkan, EC and Brentrup, D.** 2015. Bi-objective optimization of building enclosure design for thermal and lighting performance. *Building and Environment*, 92: 591–602. DOI: <https://doi.org/10.1016/j.buildenv.2015.03.039>
- Goldman, G and Zarzycki, A.** 2014. Smart Buildings/ Smart(er) Designers: BIM and the Creative Design Process. In: Kensek, K and Noble, D (eds.), *Building Information Modeling: BIM in Current Future Practice*. USA: John Wiley & Sons, 1–16. DOI: <https://doi.org/10.1002/9781119174752.ch1>
- IEA.** 2019. Global Status Report for Buildings and Construction: Towards a zero emissions, efficient and resilient buildings and construction sector.
- IES.** 2018. Table 6 Thermal Conductivity, Specific Heat Capacity and Density. Available at <https://help.iesve.com/ve2018/> [Last accessed 25 August 2020].
- Konis, K, Gamas, A and Kensek, K.** 2016. Passive performance and building form: An optimization framework for early-stage design support. *Solar Energy*, 125: 161–179. DOI: <https://doi.org/10.1016/j.solener.2015.12.020>
- MoNE.** 2020. National education statistics: Formal education 2019/'20. Available at [https://sgb.meb.gov.tr/meb\\_jys\\_dosyalar/2020\\_09/04144812\\_meb\\_istatistikleri\\_orgun\\_egitim\\_2019\\_2020.pdf](https://sgb.meb.gov.tr/meb_jys_dosyalar/2020_09/04144812_meb_istatistikleri_orgun_egitim_2019_2020.pdf) [Last accessed 02 September 2020].
- MoNE.** 2020a. Type Projects of Educational Buildings in 2020. Available at <https://iedb.meb.gov.tr/projeler/index.htm> [Last accessed 18 August 2020].
- Negendahl, K and Nielsen, TR.** 2015. Building Energy Optimization in the Early Design Stages: A Simplified Method. *Energy Buildings*, 105: 88–99. DOI: <https://doi.org/10.1016/j.enbuild.2015.06.087>
- Niemelä, T, Kosonen, R and Jokisalo, J.** 2016. Cost-optimal energy performance renovation measures of educational buildings in cold climate. *Applied energy*, 183: 1005–1020. DOI: <https://doi.org/10.1016/j.apenergy.2016.09.044>
- Sadineni, SB, Madala, S and Boehm, RF.** 2011. Passive building energy savings: A review of building envelope components. *Renewable and sustainable energy reviews*, 15(8): 3617–3631. DOI: <https://doi.org/10.1016/j.rser.2011.07.014>
- Schiavoni, S, Bianchi, F and Asdrubali, F.** 2016. Insulation materials for the building sector: A review and comparative analysis. *Renewable and Sustainable Energy Reviews*, 62: 988–1011. DOI: <https://doi.org/10.1016/j.rser.2016.05.045>
- Sghiouri, H, Mezrhab, A, Karkri, M and Naji, H.** 2018. Shading devices optimization to enhance thermal comfort and energy performance of a residential building in Morocco. *Journal of Building Engineering*, 18: 292–302. DOI: <https://doi.org/10.1016/j.job.2018.03.018>
- Stevanović, S.** 2013. Optimization of passive solar design strategies: A review. *Renewable and Sustainable Energy Reviews*, 25: 177–196. DOI: <https://doi.org/10.1016/j.rser.2013.04.028>
- Senel Solmaz, A, Halicioglu, FH and Gunhan, S.** 2018. An approach for making optimal decisions in building energy efficiency retrofit projects. *Indoor and Built Environment*, 27(3): 348–368. DOI: <https://doi.org/10.1177/1420326X16674764>
- TS 825.** 2008. The thermal insulation requirements for buildings (revision). Ankara, Turkey: Turkish Standard Institution.
- Turrin, M, von Buelow, P, Kilian, A and Stouffs, R.** 2011. Parametric modeling and optimization for adaptive architecture. *Paper presented at the Proceedings of the 2011 EG-ICE workshop*. Twente University, Netherlands, 6–8 July 2011.
- Wakili, KG, Hugi, E, Karvonen, L, Schnewlin, P and Winnefeld, F.** 2015. Thermal behaviour of autoclaved aerated concrete exposed to fire. *Cement and Concrete Composites*, 62: 52–58. DOI: <https://doi.org/10.1016/j.cemconcomp.2015.04.018>
- Wang, Y, Kuckelkorn, J, Zhao, FY, Liu, D, Kirschbaum, A and Zhang, JL.** 2015. Evaluation on classroom thermal comfort and energy performance of passive school building by optimizing HVAC control systems. *Building and Environment*, 89: 86–106. DOI: <https://doi.org/10.1016/j.buildenv.2015.02.023>
- Zhang, A, Bokel, R, van den Dobbelsteen, A, Sun, Y, Huang, Q and Zhang, Q.** 2017. Optimization of thermal and daylight performance of school buildings based on a multi-objective genetic algorithm in the cold climate of China. *Energy and Buildings*, 139: 371–384. DOI: <https://doi.org/10.1016/j.enbuild.2017.01.048>
- Zomorodian, ZS and Nasrollahi, F.** 2013. Architectural design optimization of school buildings for reduction of energy demand in hot and dry climates of Iran. *Int J Archit Eng Urban Plan*, 23(1): 41–50.

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