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Research Article

Energy Performance Optimization for A School Building in Syria According to Building Shape and Orientation

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Keywords

Energy use intensity, Building form and orientation, Optimization.

Abstract

Building shape and orientation significantly affect how buildings use energy. The objective of this study was to establish a precise process for improving building shape and orientation early in the design process. A parametric optimization workflow approach was proposed for that objective. As a case study, a primary school building in an area with a warm and dry climate was chosen. Various building shapes (simple rectangle, L shape, U shape, court shape, and square shape) were simulated using parametric energy modeling and simulation tools to determine the EUI for each shape. Utilizing the Octopus plugin, optimization was carried out on the same canvas as the parametric tool (Grasshopper). The genetic diversity of the EUI value and the orientation and glazing ratio WWR were used as the optimization process' input variables. The findings showed that the square building form with a 17° orientation angle was the best approach for achieving the most significant development in the EUI value, reaching energy efficiency improvements of up to 40%.

1. Introduction

Over 40% of the world's total energy consumption is used by buildings. Due to future energy resource limitations, this will result in a variety of issues with structures. The phrase "sustainable architectural design" has gained popularity during the past ten years. The orientation of high-performance buildings toward energy efficiency is promoted by this trend. Therefore, it is important to assess a building's performance to reduce energy consumption and improve indoor comfort.

The impact of architectural volumetric design solutions on the need for energy in buildings has recently been the subject of much investigation [1-5]. Through their aspect ratios, the design and shape of buildings can influence energy performance [6-11]. Wang et al. [12] optimized a form with a multi-sided polygon using a genetic algorithm technique. They attempted to improve the basic polygon's geometric characteristics (dimensions, angles, and many sides) through trial and error, as well as to identify some potential areas for improvement. Several building forms were investigated by Al-Anzi et al. [13] to see how they affected the thermal efficiency of office buildings in Kuwait. Their findings showed that relative compactness (RC), window-to-wall ratio (WWR), and glazing type are the main three variables that influence how much overall energy a building uses. Granadeiro et al. [14] looked at how the geometry of the building envelope affected energy efficiency. In their work, they were able to develop a parametric design approach that allows architects to assess various envelope shape designs and determine each design's energy demand. According to Mohsenzadeh et al. [15], due to receiving the least amount of solar gain, the circular shape had the highest energy performance. However, the triangular form, which affected cooling load and, as a result, the amount of energy

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consumed, was associated with the maximum amount of solar gain. In addition, the second and third biggest energy consumers and solar gain receivers, respectively, were the rectangular and square designs.

Furthermore, one of the most significant elements influencing energy usage is building orientation [16-21]. Using BIM technology, Abanda and Byers [16] examined the effect of building orientation on energy usage in a residential structure (Building Information Modelling). Their findings demonstrated that a variety of factors—such as the building envelope, building components, human behavior, building orientation, building size, and building form—impact a structure's energy requirements. The building's orientation in relation to the site impacts how it interacts with the sun, which in turn greatly influences internal solar gain. A combination of TRNSYS (a parametric simulation tool) and CONTAM energy simulation tools were used to conduct a study by Lapsia [22]. According to the findings, a building's ideal design and orientation can cut down on energy use for heating and cooling systems by as much as 81%.

Window-to-wall ratio (WWR) also directly influences both thermal comfort and energy usage [23-29]. Finding the perfect design that blends window size, orientation, and shading is crucial. According to Alsehail and Almhafdy (2020) [30], the most important components of window design to consider when determining the appropriate WWR of a building envelope are visual transmittance, thermal conductance (U-value), and climatic conditions. Additionally, in addition to WWR, window geometry (WG) and glazing characteristics also significantly affect building envelope performance [31]. According to research by Gasparella et al. [32], window orientation (WO) is also quite important and has a significant impact on structures in addition to WWR. Furthermore, the direction of construction significantly affects the amount of solar radiation received on the building's façade; solar radiation is a key factor impacting the cooling loads in buildings, according to Alshayeb et al. [33].

There are other studies that assessed the effects of building shape, relative compactness (RC), and glazing percentage on the optimal orientation of the building for improved energy performance [34-38]. Most recent research investigations rely heavily on simulation, with the bulk relying on assumptions and analysing the impact of these assumptions using numerical energy modelling.

These two crucial criteria, together with building envelope features, have been the subject of several studies in the literature, but most relied on assumptions, and their methodology did not apply to the research region that was under investigation. The goal of this study was to provide a detailed methodology for optimizing building form and orientation in school buildings with a minimum amount of energy usage and enough natural daylight in teaching rooms. The suggested workflow combines the ability to make assumptions about any building shape with optimizing the orientation and any other design parameter—WWR is taken into consideration in the study—that can aid architects and designers in the initial design stages of school buildings in any climate region.

2. Methodology

The approach for this study is separated into four key phases: form creation, energy modelling, energy simulation, and optimization process. In the Syrian city of Aleppo, a primary school building was chosen as a case study since it is located in an area with a warm and dry climate. Five primary shape geometries were proposed to include the ground covered by the study. However, the study's parametric approach also enables a user to propose any form in accordance with a preferred design. There have been suggestions for rectangular, L, U, court, and square shapes. The base case design inputs are used to simulate recommended forms, but the glass type is altered. The Grasshopper tool determines and fixes construction materials, occupancy levels, and zone programs for all recommended forms. The only variables that can change throughout the optimization process are the glass ratio and orientation parameters. To get the Energy Use Intensity (EUI) value for each recommended form, a parametric energy simulation is performed. This number is used to gauge how energy efficient a building is. The Octopus plugin, an optimization tool, is used at the last stage to complete the optimization process on the same canvas as Grasshopper. The orientation and glazing ratio-WWR with the EUI value are chosen as the variables for the optimization procedure. Consequently, the Octopus plugin's Pareto Front Method (PFM), after four generations of the optimization process, is used to determine the best options for each form.

Based on an assumed goal function of minimizing EUI value with sufficient WWR for classroom spaces, the outcomes are examined. Each shape's ideal solution is identified and explained. The findings are inferred to assist architects and designers in enhancing the size, form, and orientation of educational facilities in the research region. The steps of the study design and methodology are shown in Figure 1.

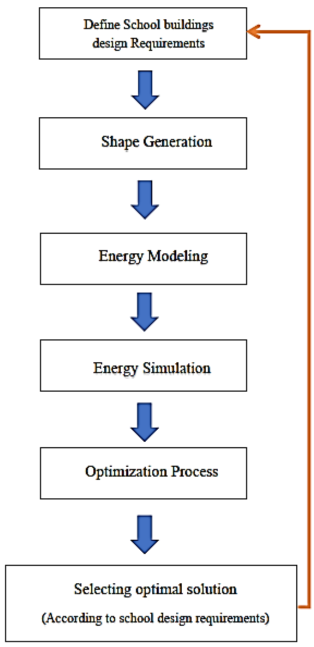

Figure 1. The general research design and stages

2.1. Case Study

To illustrate the scope of the research, a primary school building in Aleppo City, Syria, was chosen as a case study. The case study is an example of an existing educational setting in a hot and dry climate. Figure 2 depicts the location of the structure in Aleppo's southwest (a). The project was constructed in 2005 and has three major levels (Ground, First, and Second) [39]. The school's floor layout is rectangular, measuring around 43.60 and 11.10 meters in length and breadth, respectively, with a floor area of 484 m^2. Each level is 3 meters tall. The school's main facade, which is facing west, is shown in Figure 2 (b).

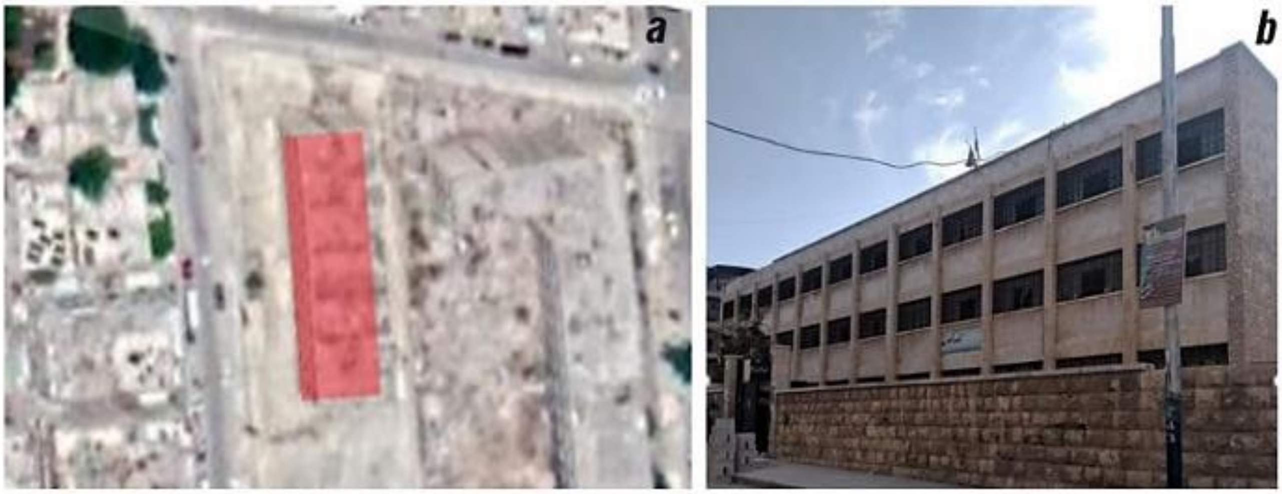

Figure 2. a) Aerial photo of the selected case b) Front elevation of the case [39]

At 36 degrees latitude and 37 degrees longitude, under a variety of climatic circumstances, Aleppo is located on the Mediterranean Sea. In the winter, it may be said to be Syria's coldest area [40]. The highest temperature is often around 24 degrees Celsius. The number of hours of sunshine each day, the number of wet days each month, the amount of precipitation in millimetres each day, and the relative humidity are all shown in Figure 3 for each month of the year.

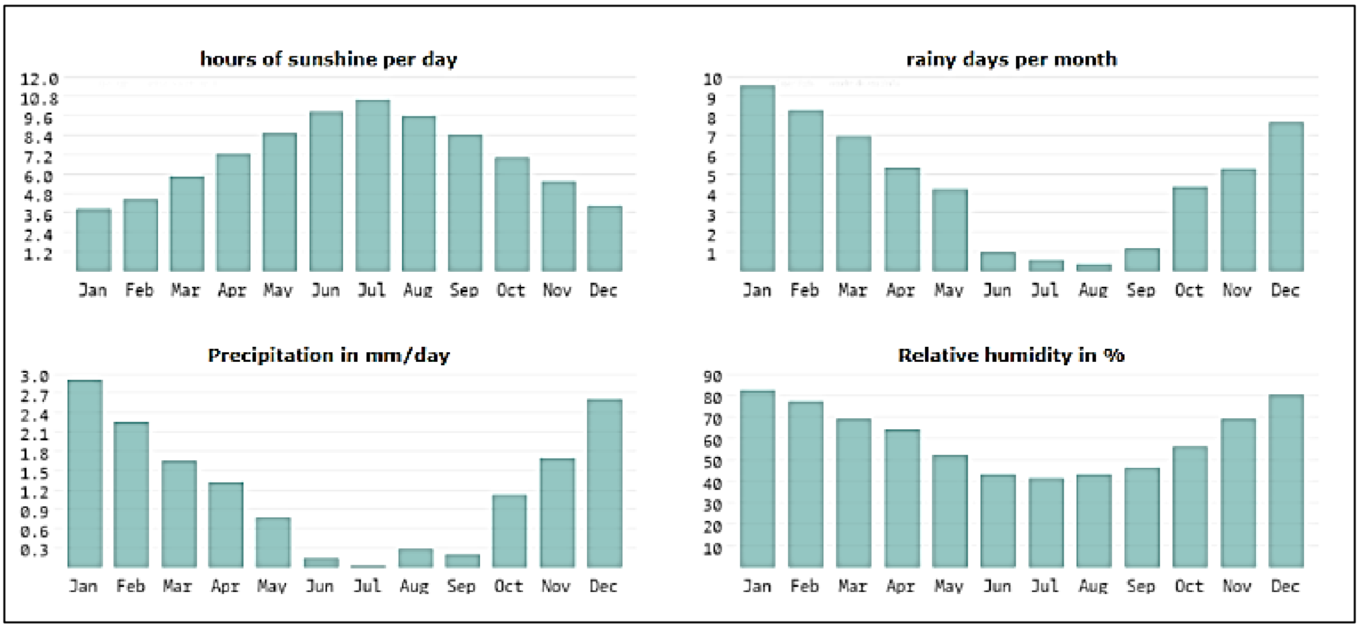

Figure 3. Aleppo climate data [40].

The structure has three major levels with a total floor space of 484 m2. The main entrance and classrooms are located on the ground floor, and the multipurpose hall and classrooms are located on the first and second floors. These floors are organized in a linear fashion with a single band corridor type and two main staircases on either side, located in the east direction. The typical plan of the current building is shown in Figure 4.

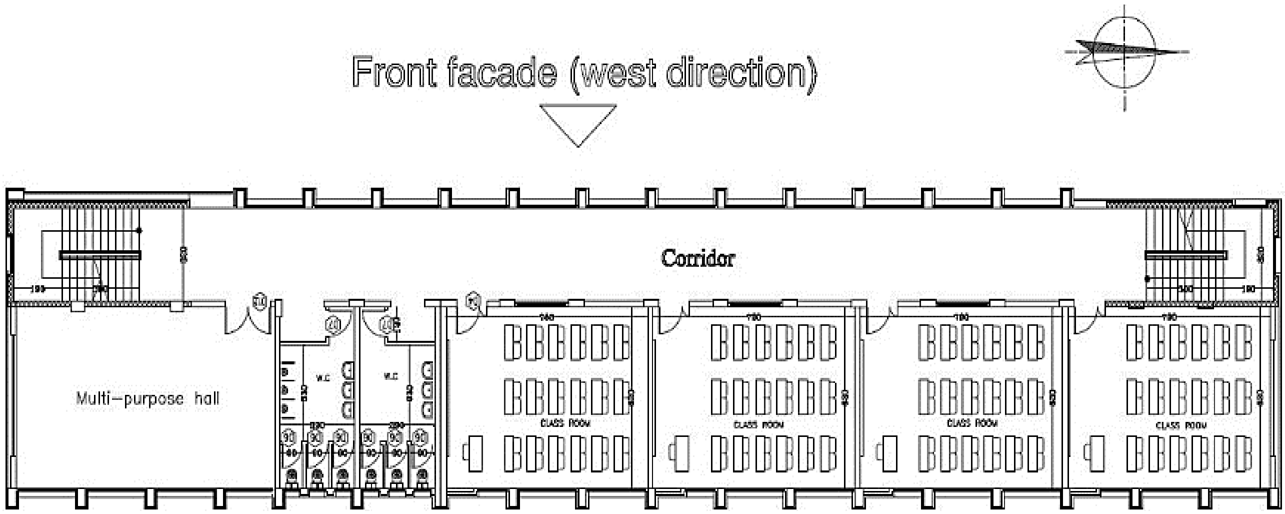

Figure 4. A typical plan of the existing school building [39].

The building's construction system is based on a reinforced concrete skeleton structure that houses the primary structural component of columns, beams, and slabs. The façade of the building is covered with natural stone. Aluminium-framed Generic PYR B Clear glass "double glass" with 13 mm middle spacing is the glazing type and window structure. The specific building materials utilized in the building envelope are listed in Table 1, along with their thermal characteristics.

According to Table 2, the building's north and south orientations have a WWR of 0.1 and 0.6, respectively.

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Table 1. Construction materials properties of the selected case [39].

	Layer	Thickness (m)	Thermal conductivity ɣ W/ (m.K)	U- Value (W/m²K)
Walls Exterior	Stone	0.1	0.840	
	XPS Extruded polystyrene	0.795	0.034	0.350
	Concrete block	0.100	0.510	
	Gypsum plastering	0.013	0.400	
	Total thickness	0.2925		
Floors	Tile ceramic	0.030	1.30	
	Screed	0.070	0.410	
	cast concrete	0.100	1.130	0.262
	UF Foam	0.1327	0.040	
	Total thickness	0.3327		
Roof	Asphalt	0.010	0.700	
	MW Glass wool	0.1445	0.040	0.197
	Aerated Concrete slab	0.200	0.160	
	Gypsum plastering	0.013	0.400	
	Total thickness	0.3675		
Glazing Type	Aluminum framed Generic PYR B Clear glass "Double glass" with 13 mm middle space.	Description: The glazing type used is an aluminum frame with Generic PYR B Clear glass 3-12-3 double glass with a U value of the middle space: 13 mm- U= 1.987		

Table 2. Glazing ratio for existing building facades

	Window to Wall Ratio			
	South facade	North facade	West facade	East façade
WWR	0.1	0.1	0.6	0.6

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Five primary architectural forms were proposed for the research. These forms will generally keep the same floor area and the same primary spaces (corridor and classrooms). For the study, Rhinoceros software [41] (Rhino 6, single-user version) was used to model a simple rectangle form, L-shape, U-shape, court shape, and square shape. It is important to note that each base case was predicated on the assumption that the glazing ratio and orientation would match those of the base cases of the existing structures. As a result, the following situations were included in the study.

Scenario 1: Changing shape geometry

In this scenario, the current case shape—a rectangular shape of 44 m in length, 10 m in width, and 12 m in height—that symbolizes the school's three levels was changed to an

L-shape, U-shape, court shape, or square shape. The recommended forms' dimensions were chosen to conserve the same amount of space in the current situation (Figure 5).

Scenario 2: Changing glass type

In this scenario, double Generic PYR B Clear glass was replaced with double low-E glass, which has a U-value of 0.27 and identical thicknesses for both existing and recommended designs.

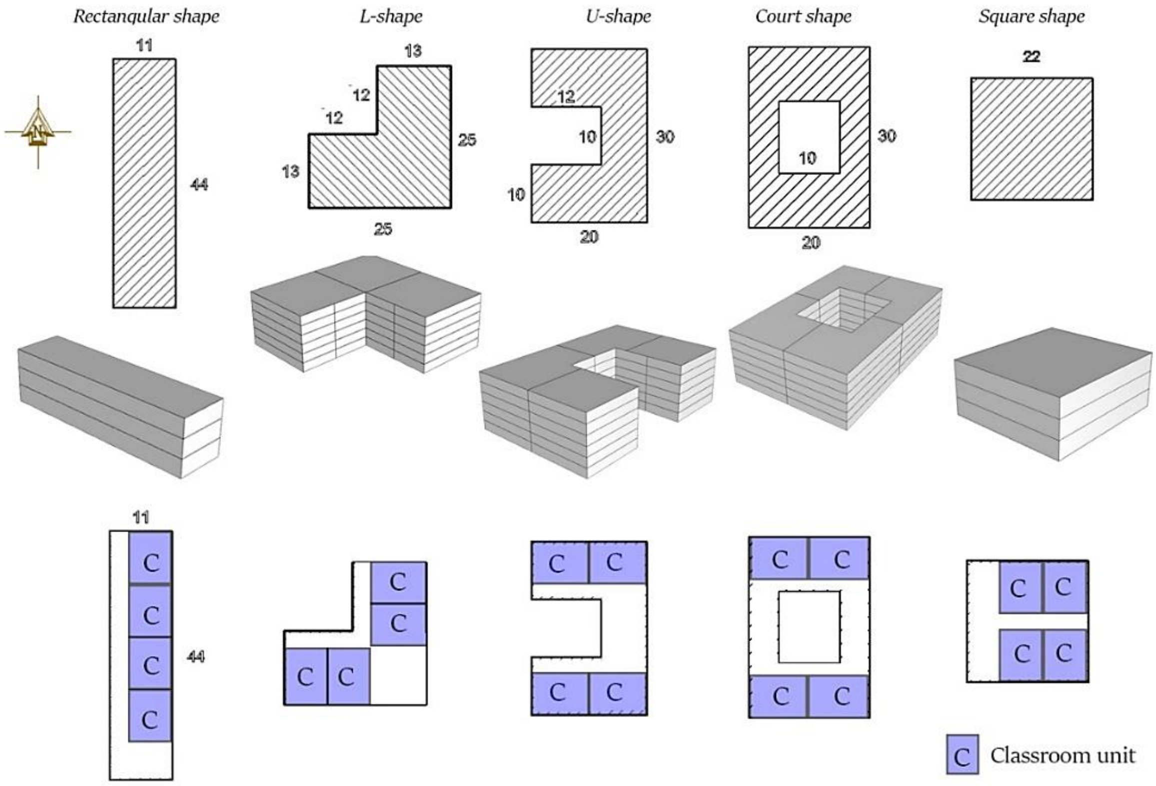

Figure 5. Typical shapes used in the study

Scenario 3: Changing Glazing Ratio and building orientation

In this scenario, the glazing ratio WWR was modified from the current ratios in each direction. The new proposed values for the current and suggested forms ranged from 0.1 to 0.9, with a 0.01 increase. Additionally, this situation called for modifying the building's orientation from its current degree. For the current and recommended forms, the new suggested values fell between 0 and 180 degrees. This scenario went through an optimization procedure as a result (Table 3).

2.1. Energy Modelling

The three major levels of the buildings' analytical zones were created as part of the energy modelling procedure. Two key zones were considered to have a substantial impact on energy performance in the study. The hallways and classrooms served as representations for these two zones. The Grasshopper [41] tool's Ladybug and Honeybee plugins were used to create analytical zones for each created form. At this stage, a zone program is assigned to each zone with a primary school zone program. Then each zone is given a zone program with a primary school zone program. In the base scenario of the described existing building, the analytical zones (walls, floors, and roofs) were given the construction materials, characteristics, and glazing type parameters. For classroom areas, heating and cooling temperature set points were established as 18 and 24 and 12 and 20, respectively. According to ASHRAE guidelines [42], these setpoints have an impact on the interior temperature after the heating and cooling systems are activated. Finally, the analytical zones were modelled and prepared for simulation. It is important to note that the energy modelling and optimization process takes construction materials and other zone factors into account. The optimization technique only changes three design parameters. The next sections will examine these factors, which include each shape's glazing type, orientation, and WWR. Additionally, it is envisaged that classrooms and corridors would face the same way as the present structure, with classrooms facing east and corridors facing west.

2.3. Energy Simulation

Using the Honeybee plugin, analytical zones for each form were created. Using the Ladybug plugin, the weather data file [40] for Aleppo was loaded. The analysis period of January to December was created using Ladybug's analysis period component. The climate of Aleppo could now be used to model the zones. The Honeybee-Generate EP

Output component was used to calculate the simulation's outputs in terms of zone energy consumption. The result of the simulation procedure included total thermal loads, a thermal load balance, heating and cooling loads, electric lighting loads, and electric fan loads. As a result, the energy simulation process was completed, and optimization was taken up in the following stage. It is essential to note that the study uses EUI as a measure of building energy efficiency. Thus, the total value of the electric loads for heating, cooling, lighting, and fans were added, and the EUI for each shape was determined to be used as a dependent variable in the optimization process throughout the analysis.

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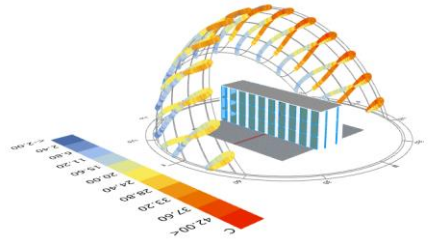
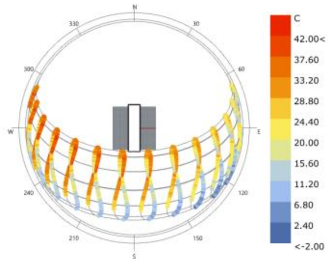
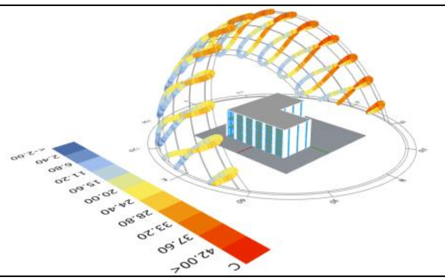
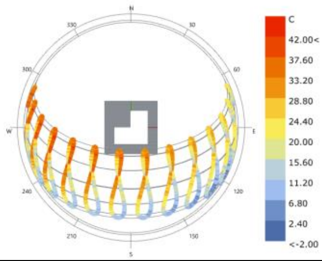
Table 3. Base cases of suggested shapes.

South WWR	North WWR	West WWR	East WWR	Orientation
0.1	0.1	0.6	0.6	0°

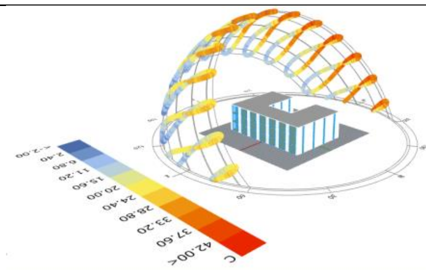
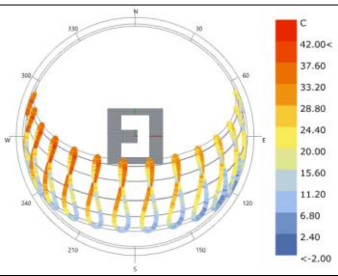
Base Case of Rectangular shape (Existing building)

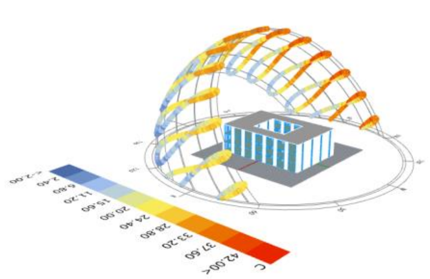
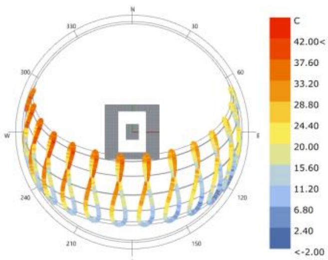
Base Case of L-shape

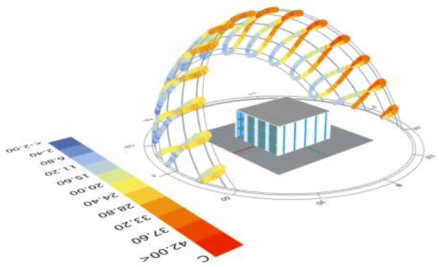
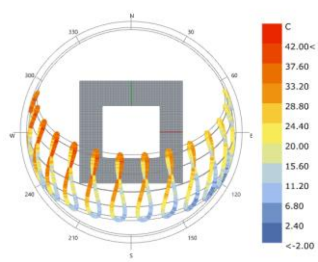
Base Case of U-shape

Base Case of Court shape

Base Case of Square shape

2.4. Optimization Process

There are several competing parameters in the form optimization process. Building orientation and glazing ratio are therefore taken into consideration as design elements. Other design criteria were set in the building's recommended forms.

There will always be independent and dependent variables to optimize in every optimization process [43]. The following were identified as the study's key optimization process variables:

Building Orientation: Independent Variable

Glazing Ratio or Wall-to-window Ratio WWR: Independent Variable.

Energy Use Intensity EUI: Dependent Variable

The term "Energy Use Intensity" (EUI) refers to how much energy a building uses overall in relation to its gross floor area. EUI can therefore serve as a gauge of a building's energy efficiency. Typically, it is determined by dividing the annual energy consumption of a building by its kWh/m^2 floor area [44]. EUI is regarded as a dependent variable in the study's process of optimization. The logical balance between EUI, WWR, and building orientation angles was determined using the Octopus plugin, which aids in optimizing design parameters in the Grasshopper program, as illustrated in Figure 3. Building orientation angle parameters vary from 0° to 180° from north-south while the WWR parameters extend from 0.1° to 0.9.

3. Results and Discussion

The study developed a parametric framework for maximizing the key design factors that influence how much energy is used in school buildings. Quite a bit of data is needed to analyse building energy efficiency. Energy is needed in buildings for ventilation, lighting, refrigeration, heating, and other functions. However, the type of building, how it operates, and hours of occupancy all affect how much energy it uses. The energy usage of buildings may then be determined with the use of energy simulation. The present study examined how much energy was used by the school buildings. The recommended parametric approach assisted in the early design phase optimization of shape, orientation, and glazing ratio characteristics that can significantly impact building energy performance during the operation of school buildings.

Both the present case and recommended forms were used to test a scenario of altering glass type. Energy Plus in Grasshopper was used to simulate the energy of the recommended forms. According to the energy modelling findings, the EUI of a rectangular shape reduced from 436.28 kWh/m^2 to 326.25 kWh/m^2 by switching from double Generic PYR B Clear glass with a U-value of 1.987 W/m2K to double low-E glass with a U-value of 0.27. According to Table 4 and Figure 6, the values of EUI for the L-shape, U-shape, court shape, and square shape were reduced from 346.89, 370.48, 400.52, and 315.48 kWh/m^2 to 293.12, 306.07, 315.64, and 271.74 kWh/m^2, respectively. Thus, it can be seen that the use of low-E glass has a significant impact on lowering energy usage in educational facilities.

Table 4. Results of EUI by changing glass type of suggested shapes

	EUI value for existing and suggested shapes kWh/m²/year				
Glass type	Rectangular	L-shape	U-shape	Court shape	Square shape
Existing glass type	436.28	346.89	370.48	400.52	315.48
Double low e glass	326.25	293.12	306.07	315.64	271.74

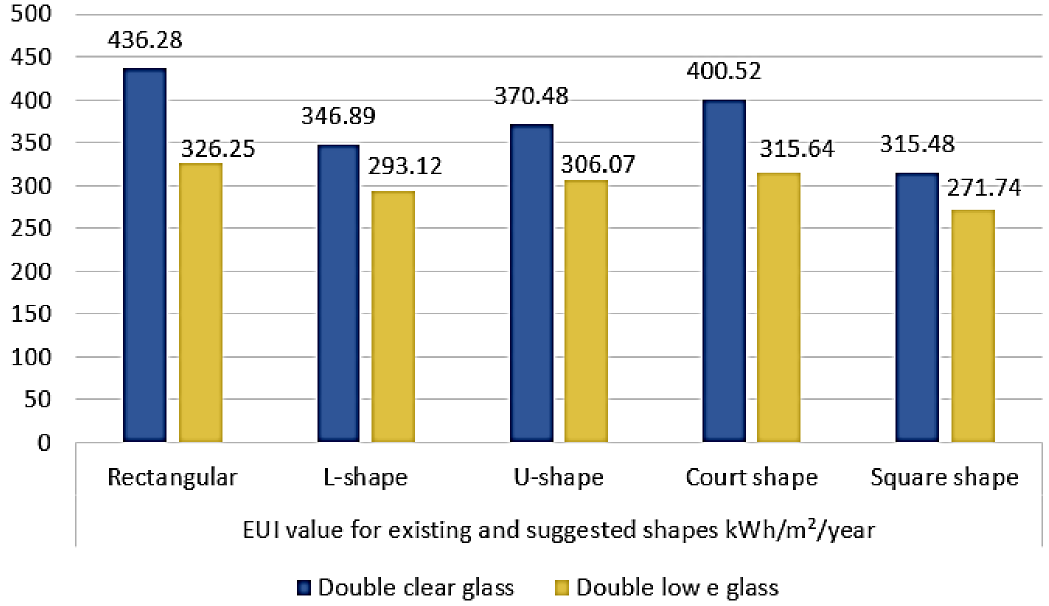


Figure 6. Results of changing glass type.

According to Figure 6, converting a rectangular shape into an L-shape while maintaining the same structural and functional characteristics led to an improvement in the energy performance of up to 20.4%, while the U-shape, court shape, and square shape achieved improvements of up to 15.0%, 8.0%, and 27.65%, respectively. On the other hand, the improvement in energy performance after switching to Low-E glass in all shapes reached up to 31.40% in a rectangular shape, 32.80% in an L-shape, 29.80% in a U-shape, 27.60% in a court shape, and 37.70% in a square shape.

It may be inferred that switching to Low-E glass for school buildings' windows in warm, dry conditions has a major impact on improving a building's energy efficiency. Figure 7 shows the improvement in energy performance for each shape relative to the previous case result after altering the glass material.

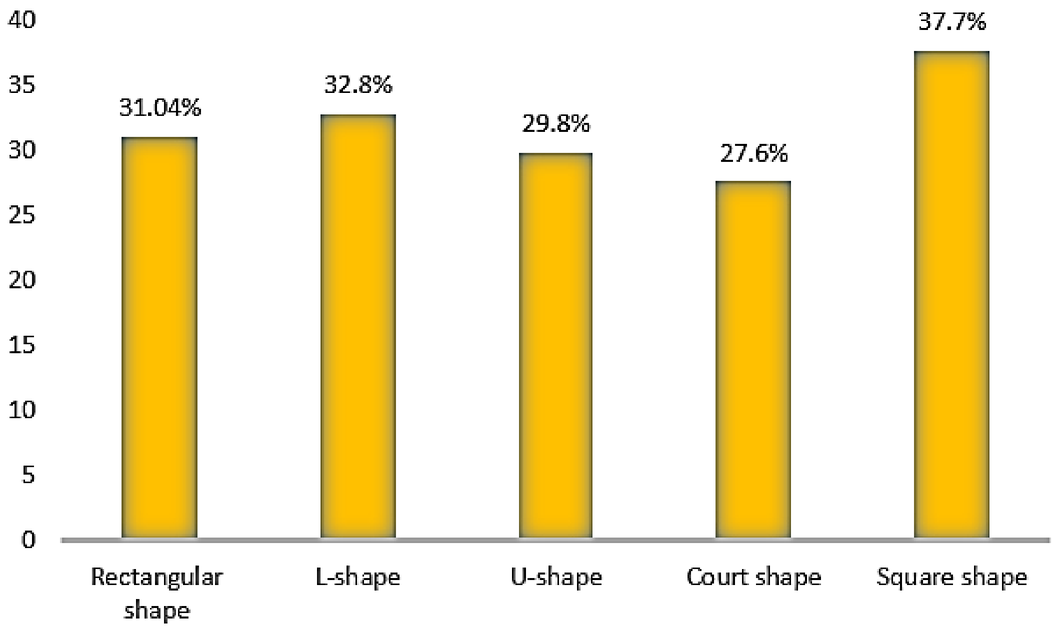


Figure 7. Percent of energy performance improvement for shapes base case compared to the existing case

Figure 7 shows that after altering the glass type, the square shape had the greatest percentage gain in energy performance. It is insufficient to merely state that the square form is the best shape for school structures in the recommended research region. To establish a balance between these characteristics and the value of EUI, design parameters and building form must both be tuned. The conceptual design phase of school buildings must also take into account a great number of other factors. These factors include giving classroom areas enough lighting and ventilation. To provide adequate daylight and reduce the danger of overheating during the summer, it is also desirable that classroom areas face north. Because of these factors, architects and designers may utilize the proposed parametric process to select the best option for their specific design characteristics.

A choice of the best solution from the obtained results—one that achieves a balance between the input variables with the least amount of EUI—was made in consideration of the aforementioned elements, particularly the location of the classroom spaces in the north direction. The following criteria were used to determine the best solution while taking classroom locations into account:

ASHRAE 90.1 Standards of daylight in school buildings

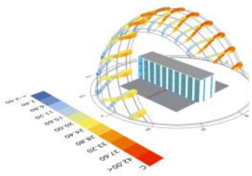
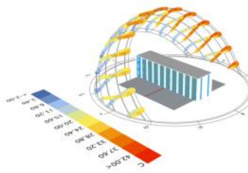
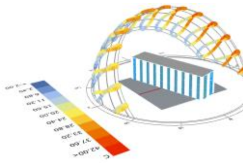
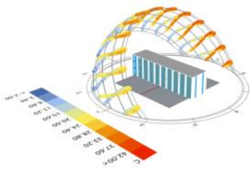
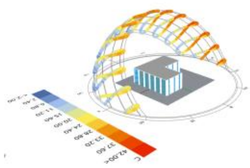
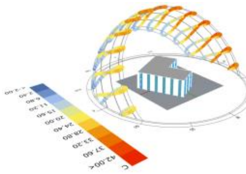
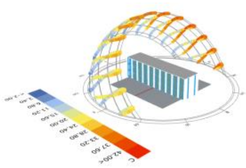
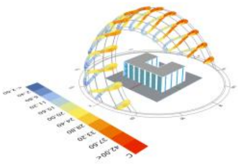
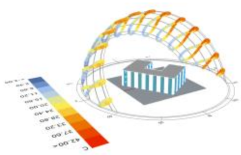
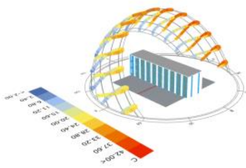
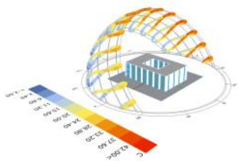
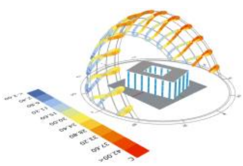
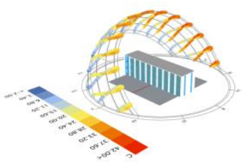
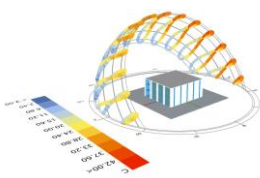
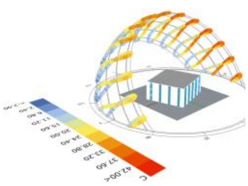
The solution is preferred to achieve the minimum value of EUI

The optimal solution is preferred to have a minimum value of WWR in the south direction.

ASHRAE 90.1 standards ensure that the area of the window openings ranges between 18% to 22% of the classroom space to ensure good ventilation and lighting in hot-dry climate regions. Accordingly, the WWR of classroom sides must fall into a range between 0.375-0.458. Depending on these values and the other criteria, the optimal solution for each suggested shape, including the rectangular shape, was selected and compared, as shown in Table 5.

As shown in Table 5 the optimal solution for each suggested shape. North WWR, Northwest, and northeast directions were investigated to get the optimal solution that achieves the purpose of providing sufficient daylight and preventing glare according to ASHRAE 90.1 standards. The selected solutions in each shape compared depended on also minimizing WWR south. The final selected optimal solution achieved the minimum value of EUI, which means having a higher energy performance.

Table 5. The selected optimum solution for each shape compared to the existing case and its base case

Existing Case EUI	Base Case (low e glass) EUI	Optimal Solution	WWR North	WWR West	WWR South	WWR East	Ori.	% Reform
The optimal solution of rectangular shape								
Existing Case EUI	Base Case (low e glass) EUI	Optimal Solution	WWR North	WWR West	WWR South	WWR East	Ori.	% Reform
			0.46	0.63	0.10	0.36	18°	30.3%
EUI (kWh/m²/y) 436.28	EUI (kWh/m²/y) 326.25	EUI (kWh/m²/y) 303.69						
The optimal solution of L shape								
Existing Case EUI	Base Case (low e glass) EUI	Optimal Solution	WWR North	WWR West	WWR South	WWR East	Ori.	% Reform
			0.38	0.46	0.62	0.30	26°	33.8%
EUI (kWh/m²/y) 436.28	EUI (kWh/m²/y) 293.12	EUI (kWh/m²/y) 288.65						
The optimal solution of U shape								
Existing Case EUI	Base Case (low e glass) EUI	Optimal Solution	WWR North	WWR West	WW R South	WWR East	Ori.	% Reform
			0.41	0.37	0.25	0.35	34°	32.5%
EUI (kWh/m²/y) 436.28	EUI (kWh/m²/y) 306.07	EUI (kWh/m²/y) 294.41						
The optimal solution of court shape								
Existing Case EUI	Base Case (low e glass) EUI	Optimal Solution	WWR North	WWR West	WW R South	WWR East	Ori.	% Reform
			0.39	0.49	0.31	0.15	14°	31.1%
EUI (kWh/m²/y) 436.28	EUI (kWh/m²/y) 315.64	EUI (kWh/m²/y) 300.26						
The optimal solution of square shape								
Existing Case EUI	Base Case (low e glass) EUI	Optimal Solution	WWR North	WWR West	WW R South	WWR East	Ori.	% Reform
			0.38	0.47	0.25	0.15	17°	39.45%
EUI (kWh/m²/y) 436.28	EUI (kWh/m²/y) 271.74	EUI (kWh/m²/y) 264.16						

4. Conclusions

The study presented a parametric optimization workflow to investigate the effect of shape and orientation on energy performance in school buildings. The study was conducted in dry and warm climate regions. The suggested parametric workflow can help architects and designers in the early design stages of buildings generally and in school buildings design, specifically in the climate region of the study area. An existing case study of a primary school building in Aleppo, Syria, was chosen to implement the workflow. Using parametric modelling and energy simulation tools, thermal loads were obtained to calculate the Energy Use Intensity EUI, which is used as an indicator of building energy performance. To achieve the research goals, five main building geometry were suggested. Simple rectangular shape, L-shape, U-shape, court shape, and square shape were used for the base cases of the study. A unique parametric algorithm was developed using Grasshopper and Ladybug tools to obtain the EUI for each shape case. First, the glazing type was changed to low-E glass type to see the effect of this kind of glass on the value of EUI in the study area. The optimization process was conducted using the Octopus plugin after determining the input variables that contain EUI (dependent variable) and orientation and glazing ratio WWR (independent variables).

To find the optimal solution, the optimization plugin (Octopus) ran for 24 hours, resulting in over180 solutions after four generations of optimal solutions for each suggested shape. These solutions were assumed to achieve an optimal balance between the input parameters. Using the Pareto Front line, optimal solutions were selected for each shape. The optimal solutions were analysed and compared depending on certain criteria that included ASHRAE 90.1 standards (related to WWR) as well as the minimum values of EUI and WWR in the south direction.

As a result, the optimal solution for each shape was chosen around the proposed criteria. The following conclusions can be reached based on the obtained results:

- Low-E glass type has a significant effect on improving school building energy performance in warm and dry climate regions.
- The optimal solution of the rectangular shape achieved up to 30.3% development in EUI value compared to the existing case with 18° orientation angle.
- The optimal solution of the L-shape achieved up to 33.8% development in EUI value compared to the existing case with 26° orientation angle.
- The optimal solution of the U-shape achieved up to 32.5% development in EUI value compared to the existing case with a 34° orientation angle.
- The optimal solution of the court shape achieved up to 30.10% development in EUI value compared to the existing case with a 14° orientation angle.
- The optimal solution of the square shape achieved up to 39.45% development in EUI value compared to the existing case with 17° orientation angle.

It can be concluded that the optimal orientation angle of school buildings ranges between 14-34° in the climate of Aleppo (warm-dry climate). Moreover, the square shape achieved a potential decrease in EUI value incorporating the design criteria in classroom spaces, thus providing the same daylight amount for classroom spaces. On the other hand, architects can choose shape geometry depending on their design preferences and the required EUI reference value of the project by following the produced workflow in the study.

Furthermore, it can be concluded that architects and designers of school buildings should avoid assumptions about shape and orientation parameters in the early design stages as much as possible. An optimization process should be conducted to investigate the optimum shape and orientation angle concerning the most important parameters that affect building energy performance. In addition, parametric energy modelling and simulation can accelerate the optimization process in the early design stages.

Within that context, the research recommends the following for future investigations:

- Considering more design parameters, such as shading devices in the optimization process of school buildings' shape and orientation, could improve energy performance in warm and dry climate regions.
- Multi-objective optimization process that includes energy performance and daylight performance alongside more design parameters could be performed in future studies to get more investigation and optimal solution.

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References

[1] B. Raof, The correlation between building shape and building energy performance, Int. J. Adv. Res 5 (2017) 552–561.
[2] M. Premrov, M. Žigart, V.Ž. Leskovar, Influence of the building shape on the energy performance of timber-glass buildings located in warm climatic regions, Energy 149 (2018) 496–504.
[3] J. Parasonis, A. Keizikas, D. Kalibatiene, The relationship between the shape of a building and its energy performance, Architectural Engineering and Design Management 8(4) (2012) 246–256.
[4] A. Ordoñez, J. Carreras, I. Korolija, Y. Zhang, A. Coronas, Impact of building geometry on its energy performance depending on climate zones, Proceedings of the BSO14: Second Building Simulation and Optimization Conference, London, UK, (2014) 23–24.
[5] Y. Fang, S. Cho, Design optimization of building geometry and fenestration for daylighting and energy performance, Solar Energy 191 (2019) 7–18.
[6] D.G. Zenginis, K.J. Kontoleon, Influence of orientation, glazing proportion and zone aspect ratio on the thermal performance of buildings during the winter period, Environmental Science and Pollution Research 25(27) (2018) 26736–26746.
[7] F. Nazari, W. Yan, Convolutional versus Dense Neural Networks: Comparing the Two Neural Networks Performance in Predicting Building Operational Energy Use Based on the Building Shape, arXiv preprint arXiv:2108.12929 (2021).

[8] F. Mostafavi, M. Tahsildoost, Z. Zomorodian, Energy efficiency and carbon emission in high-rise buildings: A review (2005-2020), Building and Environment 206 (2021) 1-18.
[9] A. Jazayeri, M. Aliabadi, The effect of building aspect ratio on the energy performance of dormitory buildings in cold and semi-arid climates of Iran, International Conference on Sustainability, Green Buildings. Environmental Engineering and Renewable Energy,(SGER 2018), Malaysia, 2018.
[10] T.L. Hemsath, K.A. Bandhosseini, Sensitivity analysis evaluating basic building geometry's effect on energy use, Renewable Energy 76 (2015) 526–538.
[11] C. Koranteng, E. Abaitey, The effects of form and orientation on energy performance of residential buildings in Ghana, Journal of Science and Technology (Ghana) 30 (2010).
[12] W. Wang, H. Rivard, R. Zmeureanu, Floor shape optimization for green building design, Advanced Engineering Informatics 20 (2006) 363–378.
[13] A. AlAnzi, D. Seo, M. Krarti, Impact of building shape on thermal performance of office buildings in Kuwait, Energy Conversion and Management 50 (2009) 822–828.
[14] V. Granadeiro, J.P. Duarte, J.R. Correia, V.M. Leal, Building envelope shape design in early stages of the design process: Integrating architectural design systems and energy simulation, Automation in construction 32 (2013) 196–209.
[15] M. Mohsenzadeh, M.H. Marzbali, M.J.M. Tilaki, A. Abdullah, Building form and energy efficiency in tropical climates: A case study of Penang, Malaysia, urbe. Revista Brasileira de Gestão Urbana 13 (2021).
[16] F. Abanda, L. Byers, An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling), Energy 97 (2016) 517–527.
[17] M. Karimimoshaver, M.S. Shahrak, The effect of height and orientation of buildings on thermal comfort, Sustainable Cities and Society 79 (2022) 1–11.
[18] E. Erebor, E. Ibem, I. Ezema, A. Sholanke, Energy Efficiency Design Strategies in Office Buildings: A Literature Review, IOP Conference Series: Earth and Environmental Science, IOP Publishing, (2021) 1–14.
[19] W. Khaliq, U.B. Mansoor, Performance evaluation for energy efficiency attainment in buildings based on orientation, temperature, and humidity parameters, Intelligent Buildings International (2021) 1–17.
[20] S. Tokbolat, R. Tokpatayeva, S.N. Al-Zubaidy, The Effects of Orientation on Energy Consumption in Buildings in Kazakhstan, Journal of Solar Energy Engineering 135 (2013).
[21] N.A. Naamandadin, A.R. Sapian, S.N.A. Mohd Noor, Site planning and orientation for energy efficiency: A comparative analysis on three office buildings in Kuala Lumpur to determine a location for building shading device, Key Engineering Materials, Trans Tech Publ, (2016) 247–255.
[22] R. Lapisa, The effect of building geometric shape and orientation on its energy performance in various climate regions, GEOMATE Journal 16 (2019) 113–119.
[23] N. Ziaee, R. Vakilinezhad, Multi-objective optimization of daylight performance and thermal comfort in classrooms with light-shelves: Case studies in Tehran and Sari, Iran, Energy and Buildings 254 (2022) 1–21.
[24] L. Zhu, B. Wang, Y. Sun, Multi-objective optimization for energy consumption, daylighting and thermal comfort performance of rural tourism buildings in north China, Building and Environment 176 (2020) 1–14.
[25] B.S. Qurraie, B. Kıraç, Evaluation of energy efficiencies of double skin façade systems and double skin green façade systems in Turkey, International Journal of Environmental Studies (2022) 1–15.
[26] S. Mirrahimi, M.F. Mohamed, L.C. Haw, N.L.N. Ibrahim, W.F.M. Yusoff, A. Aflaki, The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate, Renewable and Sustainable Energy Reviews 53 (2016) 1508–1519.
[27] Z. Liu, D. Wu, J. Li, H. Yu, B. He, Optimizing building envelope dimensions for passive solar houses in the Qinghai-Tibetan region: window to wall ratio and depth of sunspace, Journal of Thermal Science 28 (2019) 1115–1128.
[28] B. Qurraie, F. Beyhan, Investigating the Effect of Stained-glass Area on Reducing the Cooling Energy of Buildings (Case Study: Ankara), Computational Research Progress In Applied Science & Engineering 8 (2022).
[29] B.S. Qurraie, Smart Window Design Tool: Daylight Transmission by Using Transparent Color Filters, Computational Research Progress in Applied Science & Engineering 08 (2022).
[30] A. Alsehail, A. Almhafdy, The Effect of Window-to-Wall Ratio (WWR) and Window Orientation (WO) on the Thermal Performance: A preliminary overview, Environment-Behaviour Proceedings Journal 5 (2020) 165–173.
[31] N. Harmati, Z. Magyar, Influence of WWR, WG and glazing properties on the annual heating and cooling energy demand in buildings, Energy Procedia 78 (2015) 2458–2463.
[32] A. Gasparella, G. Pernigotto, F. Cappelletti, P. Romagnoni, P. Baggio, Analysis and modelling of window and glazing systems energy performance for a well insulated residential building, Energy and Buildings 43 (2011) 1030–1037.
[33] M. Alshayeb, H. Mohamed, J.D. Chang, Energy analysis of health center facilities in Saudi Arabia: Influence of building orientation, shading devices, and roof solar reflectance, Procedia engineering 118 (2015) 827–832.
[34] S. Pathirana, A. Rodrigo, R. Halwatura, Effect of building shape, orientation, window to wall ratios and zones on energy efficiency and thermal comfort of naturally ventilated houses in tropical climate, International Journal of Energy and Environmental Engineering 10(1) (2019) 107–120.
[35] M. Mokrzecka, Influence of building shape and orientation on heating demand: simulations for student dormitories in temperate climate conditions, E3S Web of Conferences, EDP Sciences (2018)1–8.
[36] R. Fallahtafti, M. Mahdavinejad, Optimisation of building shape and orientation for better energy efficient architecture, International Journal of Energy Sector Management (2015).
[37] N.A.M. Al-Tamimi, S.F.S. Fadzil, W.M.W. Harun, The effects of orientation, ventilation, and varied WWR on the thermal performance of residential rooms in the tropics, Journal of Sustainable development 4 (2011) 142–149.
[38] A. Ciardiello, F. Rosso, J. Dell'Olmo, V. Ciancio, M. Ferrero, F. Salata, Multi-objective approach to the optimization of shape and envelope in building energy design, Applied energy 280 (2020) 1–19.
[39] Difference, Education News, 2021. https://www.difference.news/edu/ % (Accessed 02.02.2022 2022)
[40] WorldInfo, Climate in Aleppo (Syria), 2021. https://www.worlddata.info/asia/syria/climate-aleppo.php/. (Accessed 30.10.2021 2021).
[41] B. Suits, The grasshopper-: games, life and utopia, Broadview Press 2014.
[42] ASHRAE, Handbook of Fundamentals, American Society of Heating, Air Conditioning, and Refrigerating Engineers , Inc., Atlanta, 2009.
[43] K. Lakhdari, L. Sriti, B. Painter, Parametric optimization of daylight, thermal and energy performance of middle school classrooms, case of hot and dry regions, Building and Environment 204 (2021) 1–17.
[44] M. Samadi, J. Fattahi, Energy use intensity disaggregation in institutional buildings–A data analytics approach, Energy and Buildings 235 (2021) 1–11.