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Investigating the Effect of Window Configuration on Visual Health Benefits and Energy Consumption in Educational Space

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Abstract

Introduction: In hot-arid climates, optimizing window design is crucial for balancing energy and visual comfort, which can affect environmental health and efficiency in educational buildings.

Methods: A single south-facing classroom (8 m×6 m×3 m) in Kerman was simulated using DesignBuilder software. Variables included Window-to-Wall Ratio (WWR: 10%–60%), number of windows (1–5), and orientation (horizontal vs. vertical). Energy consumption (site, source, heating, cooling loads) and Daylight Factor (DF) were evaluated for 60 models.

Results: No model with 10% WWR achieved the minimum required DF (≥2%). With 20% WWR, only 1–2 vertical windows met DF≥2%, with 1 vertical window being optimal (the lowest source energy: 376.82 kW.h). With 30% WWR, 5 vertical windows were optimal (source energy: 383.86 kW.h, DF: 2.609%). With 40% WWR, 5 vertical windows performed best (source energy: 402.33 kW.h, DF: 3.965%). With 50% WWR, 4 horizontal windows were optimal (source energy: 414.41 kW.h, DF: 2.146%). With 60% WWR, 5 horizontal windows were optimal (source energy: 429.48 kW.h, DF: 2.566%). Cooling load had a greater influence on total energy consumption than heating load.

Conclusion: In hot-arid climates like Kerman, vertical windows are more efficient at lower WWRs (20%–40%), while horizontal windows perform better at higher WWRs (50%–60%). The overall optimal configuration was 20% WWR with one vertical window, providing minimal energy consumption, which creates environmental health in terms of daylight comfort.

Keywords: Daylighting, Energy efficiency, Window design, Classroom, Design builder

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Introduction

The primary concern of architects is to create space and three-dimensional forms to fulfill human activities in that space (1).Lack of harmonization between buildings and the environment causes bioclimatic and ecological problems (2). Climate change, driven by fossil fuel dependence, presents a significant problem for construction, particularly in energy-intensive regions like arid climates (3). Over half of the total electricity consumption is used in buildings. Air-conditioning and electric lighting are the two main resources of electricity consumption. One way to reduce electricity consumption would be to limit heat gain into buildings, and subsequently reduce the demand for air-conditioning during hot summer months, especially in hot regions. On the other hand, natural daylight can be used to reduce the use of electricity for artificial lighting (4).

Daylight has long been associated with various health benefits, yet much of the evidence remains associative rather than conclusively proven. A systematic review by Aries et al. (2015) examined the scientific literature on daylight exposure and human health, revealing that while direct, statistically significant proof is limited, a broader search using specific health terms identified a range of physiological and psychological effects. These include positive outcomes such as reduced myopia, eyestrain, seasonal affective disorder, and improved sleep and cognitive performance, alongside potential risks including triggered migraines and epilepsy. The review underscores the need for more rigorous research—particularly studies that quantify actual daylight exposure and isolate its effects from electric lighting—before definitive design guidelines can be established. Nevertheless, the findings offer a preliminary foundation for integrating healthconscious daylight strategies into building design (5).

Optimizing façade design significantly improves indoor quality and reduces energy use in sunny areas like Kerman, Iran. Yazhari Kermani et al. (2018) found the optimal configurations with WWR of 50–70% and strategic overhangs enhance daylight performance and minimize glare.

The study demonstrates that thoughtful integration of shading devices and glazing ratios can improve visual comfort and reduce energy demand, offering practical guidance for daylight-efficient office design in arid climates (6).

Producing available daylight in the building is a crucial issue for reasons of energy-efficiency as well as improvement of occupants' health and well-being. New design techniques have been recently used in the design phases of buildings to adapt to human thermal comfort. Due to the wide range of energy consumption within a building, it is impossible to make a proper decision about the impact of different energy efficiency strategies (7).

Thermal comfort in classrooms significantly influences student well-being and learning. Research indicates existing models underestimate children's thermal sensations, necessitating tailored strategies to address their unique comfort needs and maintain optimal classroom temperatures.

The study revealed that existing thermal comfort models underestimated children's actual thermal sensation. The findings emphasized the significance of considering children's sensitivity to indoor temperature changes and highlighted the importance of maintaining comfortable temperatures in classrooms (8).

Dasgupta et al. focused on the operational performance of newly built schools in the UK and identified key issues related to energy consumption and indoor environmental quality. The study underscored the challenges in designing energy-efficient school buildings that provide optimal thermal comfort, acoustics, indoor air quality, and lighting. The research highlighted the need for a better understanding of how to create learning spaces that support changing pedagogical practices and promote a conducive learning environment (9).

Decentralized ventilation systems improved classroom air quality significantly, but needed enhanced humidity control and noise management for optimal thermal comfort. Effective strategies are essential.

Overall, the literature review of the provided research papers underscores the critical role of thermal comfort in school classrooms. By addressing the unique thermal needs of students, optimizing indoor temperature conditions, and ensuring adequate ventilation, schools can create a supportive learning environment that promotes student well-being, productivity, and overall academic success. Researchers can leverage these insights to further investigate and implement strategies to enhance thermal comfort in school settings. Several studiesClick or tap here to enter text. focused on the crucial aspect of thermal comfort in school classrooms using Design Builder simulation (10-12). Schools are significant energy consumers, and ensuring thermal comfort for students is essential for their well-being and productivity. The studies highlight the impact of indoor thermal conditions on energy consumption in educational buildings, especially in hot-arid climates like Egypt and Jordan. By utilizing dynamic building energy simulation models through DesignBuilder software, the researchers could assess indoor thermal comfort status, energy consumption patterns, and the performance of various HVAC systems in school buildings. The findings emphasize the need for optimizing energy consumption while maintaining a thermally comfortable environment for students, which can be achieved through design optimization, efficient HVAC systems, and regulatory criteria for school building facades. These studies provide valuable insights for researchers aiming to enhance thermal comfort and energy efficiency in school classrooms.

The literature review on the validation of Design Builder software in thermal comfort highlights the importance of occupant-centric key performance indicators (KPIs) in building design and operations. According to the study by Liu et al. (13), occupant-centric metrics are crucial for informing building design and operations, covering aspects such as resource use, indoor environmental quality, and human-building interactions. This is further supported by Moktan et al. (14), who emphasize the significance of thermal comfort in educational buildings in Nepal and the use of passive design measures to improve student comfort. Furthermore, Sadeghian et al. (15) investigated the impact of diffuse ceiling ventilation systems on thermal comfort conditions, highlighting the importance of design parameters in achieving optimal comfort levels. Similarly, Longhitano et al. (16) investigated the microclimate in a conference room with thermal stratification, emphasizing the role of HVAC systems in maintaining comfort levels. Moreover, Shrestha et al. (17) focused on the thermal environment of school buildings in Nepal and the benefits of passive design measures in enhancing student comfort. They demonstrated that the use of simulation tools like DesignBuilder software is effective in evaluating and improving thermal performance. Lastly, d'Ambrosio et al. (18) addressed the discrepancies in energy consumption calculations and thermal comfort assessments in building simulations using different software tools. In conclusion, the literature review provides valuable insights into the validation of Design Builder software in thermal comfort assessments. The studies emphasize the importance of occupant-centric KPIs, passive design measures, and HVAC systems in achieving optimal thermal comfort in various building types. Researchers can benefit from these findings to enhance their understanding of thermal comfort validation and design strategies for improved building performance.

Various studies have explored the correlation between window configuration and thermal comfort in classrooms, particularly in hot and arid regions like Kerman City (19), emphasizing that window parameters such as shape, design, size, position, and orientation significantly impact thermal comfort, energy consumption, and environmental effects in hot climates (20). In summary, the configuration of windows in classroom buildings in hot and arid regions like Kerman City is a crucial factor influencing thermal comfort, energy consumption, and the productivity and well-being of occupants. This study aimed to investigate the window area and window configuration in education spaces of Kerman city to meet at least energy consumption, which significantly affects environmental health.

Materials and Methods

Research methodology with software simulation like Design Builder has been a topic of interest in recent years, as researchers aim to enhance their understanding of built environmental issues and optimize design processes (21). De Vita et al. (2020) introduced Design Builder software and highlighted its computational simulation capacity in dealing with built environmental issues. The study emphasized the importance of utilizing simulation software like Design Builder to ensure high compatibility with restoration and seismic guidelines, as well as meeting new building environmental performance requirements. Hashemian et al. (22) focused on the optimization of retrofit measures for historical structures using dynamic models and energy simulations with Design Builder software. The research highlighted the need for studies based on the best practices to enhance architectural heritage and improve environmental performance. By integrating non-destructive surveys and preliminary analyses into special design tools, the methodology presented in the study showed the potential of Design Builder in achieving energy-saving goals for historical buildings. In a study by Hashemian et al. (23), a dynamic modeling and design optimization approach for a front-loading washing machine was presented. The research utilized parametric simulation with Design Builder software to analyze the vibrational characteristics of the washing machine. The study demonstrated the effectiveness of Bayesian Optimization in finding optimal design values for vibration reduction, indicating the computational efficiency of using simulation software for design optimization. Fouly et al. (24) explored the concept of net zero carbon building (NZCB) in hot arid climates, focusing on the development of an experimental methodology using Design Builder software. The study conducted simulations on residential units to examine the impact of passive and active techniques on carbon emissions and energy consumption. The results indicated a significant reduction in carbon emissions and energy consumption when integrating passive and active systems in the early design phase, highlighting the importance of using simulation software, like Design Builder for achieving net-zero carbon targets in challenging climates. Overall, the research papers reviewed emphasize the significance of research methodology with software simulation like Design Builder in addressing built environmental issues, optimizing design processes, and achieving energy-saving goals. By utilizing simulation software effectively, researchers can enhance their understanding of complex design problems and develop sustainable solutions for the built environment.

Process of Modelling and Simulation

In this research, the classroom with dimensions of 8 × 6 × 3 m was modeled as a base model, which has been used in the research by Daei Parizi et al. (25) for investigating daylight conditions in classrooms in Kerman city of Iran (Figure 1). In all modeled classrooms, windows are located in south facing external wall.

Construction details of the modeled classroom, such as material construction, thickness, and U-value of external wall, roof, floor, and window were specified based on Table S1, which were common in Kerman city.

In the basic model of this research, different window configurations and window-to-wall ratio (WWR) were applied. Each of the classes was modeled in Design Builder software with different WWRs (10 to 60%) and with 1 to 5 windows, while being developed both horizontally and vertically. Furthermore, the valid weather data of Kerman city was uploaded in Design Builder.

Therefore, 30 classrooms with horizontal windows from 10 to 60% WWR and 30 classrooms with vertical windows from 10 to 60% WWR, were simulated separately, and the amount of source energy, site energy cooling, and heating load were recorded for each class, as well as, daylight factor (DF) to evaluate and analyze energy consumption and daylight condition of all models concurrently.

After the final evaluation, classrooms with a sufficient DF, which consume lower source energy, can be recognized as the optimum model of classroom.

Results

The amount of source and site energy, heating and cooling load of all classroom models with 10% to 60% WWR when located horizontally and vertically with different numbers of windows are presented in Tables 1 to 6 separately.

Table 1 shows the amount of energy consumption in models with a window area of 10% of the external wall that has 1 to 5 windows. These windows were placed horizontally in some models and vertically in some models. The amount of energy consumption was measured in

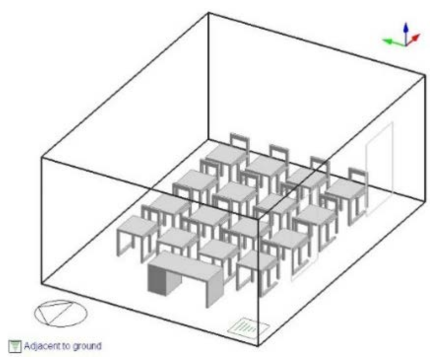


Figure 1. The classroom modeled in Design Builder

two modes, energy site and energy source. It can be seen that the amount of energy consumption (both site and source energy) decreased with increasing the number of windows. However, the amount of heating load increased with increasing the number of windows from 1 to 5 while the amount of WWR remains constant (10%), while the amount of cooling load decreased; therefore, the amount of source energy decreased because of more dependency of source energy to the cooling load with respect to the heating and cool loads.

As shown in Table 2, the site and source energy consumption, as well as heating and cooling load in the classroom models with 20% WWR, are obtained. In this table, the amount of energy consumption decreased with increasing the number of windows, but the amount of heating loads increased. It should be noted that the amount of heat load increases with increasing number of windows, but the cooling load decreases with increasing number of windows. Totally, energy consumption decreased with increasing number of windows both horizontally and vertically.

As shown in Table 3, the amount of heat load decreased with increasing the number of windows from 22 to 25 kW.h, while 30% WWR was applied for all classroom models. However, the amount of cooling load changed from 7362 to 7163 kW.h, indicating a significant decrease with increasing the number of windows, therefore, total site and source energy reduced with increasing the number of windows when they developed both horizontally and vertically, when in all models, the amount of WWR was considered constant with 30%.

Table 3 shows site and source energy consumption, heating and cooling load in the classroom with 40% WWR when different number of windows were applied horizontally and vertically. As shown in this table, the heating load increased (2 kW.h) with increasing the number of windows, but the cooling load decreased significantly (220 kW.h). Therefore, it can be inferred that the total source and site energy decrease with decreasing the number of windows when 40% WWR is the same parameter in all models.

Table 5 shows the energy site, energy source, cooling load, and heating load in classrooms with 50% WWR and various number of windows (one to five). As shown in this table, the heating load increased with increasing the number of windows, both horizontally and vertically,

Table 1. Amount of energy consumption in the classroom with 10% WWR, according to different numbers of windows horizontally and vertically

	10% window area to the external wall			
	Total Source Energy	Total Site Energy	Heating	Cooling
1 horizontal window	357.26	218.36	80.75	6032.23
1 vertical window	358.5	220.12	71.7	6107.11
2 horizontal windows	354.81	214.81	99.73	5880.31
2 vertical windows	358.88	220.54	70.75	6123.77
3 horizontal windows	353.23	211.49	127.93	5727.73
3 vertical windows	356.52	217.6	81.58	6002.93
4 horizontal windows	350.87	208.56	138.63	5607.31
4 vertical windows	355.59	216.38	86.98	5951.7
5 horizontal windows	350.59	207.87	145.22	5574.82
5 vertical windows	354.73	215.18	92.78	5901.06

Table 2. Amount of energy consumption in the classroom with 20% WWR according to different numbers of windows, both horizontally and vertically

	20% window area to the external wall			
	Total Source Energy	Total Site Energy	Heating	Cooling
1 horizontal window	371.19	234.15	40.61	6663.63
1 vertical window	376.82	240.06	31.6	6893.92
2 horizontal windows	368.1	230.62	49.81	6522.28
2 vertical windows	377.58	234.16	39.36	6665.05
3 horizontal windows	364.69	226.64	61.51	6361.31
3 vertical windows	369.74	232.7	41.9	6607.81
4 horizontal windows	361.51	222.72	75.47	6200.79
4 vertical windows	368.96	231.79	44.47	6571.35
5 horizontal windows	358.71	218.94	93	6041.62
5 vertical windows	367.66	230.38	47.16	6515.84

Table 3. Amount of energy consumption in the classroom with 30% WWR according to different number of windows, both horizontally and vertically

	30% window area to the external wall			
	Total Source Energy	Total Site Energy	Heating	Cooling
1 horizontal window	389.11	252.33	22.02	7362.59
1 vertical window	396.47	259.62	17.17	7640.51
2 horizontal windows	384.91	248.02	27.15	7196.14
2 vertical windows	400.02	251.82	21.6	7344
3 horizontal windows	380.66	243.62	32.93	7025.76
3 vertical windows	386.96	250.24	22.84	7283.76
4 horizontal windows	377.06	239.82	38.95	6877.41
4 vertical windows	385.41	248.68	24.27	7223.76
5 horizontal windows	371.11	233.43	50.57	6626.66
5 vertical windows	383.86	247.12	25.73	7163.87

Table 4. Amount of energy consumption in the classroom with 40% WWR according to different number of windows, both horizontally and vertically

	40% window area to the external wall			
	Total Source Energy	Total Site Energy	Heating	Cooling
1 horizontal window	408.29	271.08	13.01	8073.9
1 vertical window	418.27	280.7	10.4	8436.57
2 horizontal windows	403.96	266.75	16.51	7908.21
2 vertical windows	407.28	270.11	13.19	8037.38
3 horizontal windows	399.47	262.28	19.85	7737.6
3 vertical windows	405.63	268.5	13.94	7976.22
4 horizontal windows	394.96	257.76	23.7	7564.49
4 vertical windows	403.97	266.88	14.71	7914.91
5 horizontal windows	390.48	253.23	28.04	7390.55
5 vertical windows	402.33	265.28	15.53	7853.94

Table 5. Amount of energy consumption in the classroom with 50% WWR according to different number of windows, both horizontally and vertically

	50% window area to the external wall			
	Total Source Energy	Total Site Energy	Heating	Cooling
1 horizontal window	427.95	289.93	9.46	8783.04
1 vertical windows	438.97	300.44	8.44	9177.62
2 horizontal windows	423.57	285.67	11.26	8621.75
2 vertical windows	426.51	288.56	9.57	8731.78
3 horizontal windows	419.11	281.34	12.93	8457.93
3 vertical windows	424.82	286.94	9.88	8670.58
4 horizontal windows	414.41	276.7	15.68	8281.65
4 vertical windows	423.12	285.3	10.25	8609.04
5 horizontal windows	409.79	272.15	18.52	8108.27
5 vertical windows	421.42	283.68	10.58	8547.92

Table 6. Amount of energy consumption in the classroom with 60% WWR according to different number of windows, both horizontally and vertically

	60% window area to the external wall			
	Total Source Energy	Total Site Energy	Heating load	Cooling load
1 horizontal windows	447.48	308.52	8.02	9480.63
1 vertical windows	458.523	321.21	7.37	9956.35
2 horizontal windows	443.26	304.45	9.3	9326.67
2 vertical windows	437.07	298.62	8.69	9109.33
3 horizontal windows	438.8	300.13	10.7	9163.69
3 vertical windows	433.84	295.54	9.06	8993.47
4 horizontal windows	434.18	295.67	12.05	8995.39
4 vertical windows	430.62	292.46	9.46	8877.72
5 horizontal windows	429.48	291.12	13.51	8823.58
5 vertical windows	427.39	289.38	9.9	8761.82

but the cooling load decreased significantly. As a result, it can be inferred that the energy source and energy site were significantly reduced by increasing the number of windows in the external wall while the number of windows increased both horizontally and vertically, and the window area of all models remained constant at 50%.

Table 6 shows the energy, heating, and cooling load for classes with 50% window area, while the number of windows increased from 1 to 5 horizontally and vertically. As shown in Table 6, the heating load increased with increasing the number of windows. However, the cooling load decreased significantly with increasing the number of windows. Also, the amount of energy source and energy site reduced with increasing the number of windows, while the window area was considered the same in all models, as 60% WWR.

After analyzing the amount of energy consumption and heating and cooling loads in all the models evaluated in the research, according to the research conducted in the same field that had previously examined the amount of light in similar models, the results of that research were compared with the results of the present research. With this comparison, it can be concluded that which of the models, while providing the amount of light needed to establish light comfort conditions, still have favorable conditions in terms of energy consumption.

According to Table S2, it can be inferred that vertical windows in the classroom with 10% WWR had the potential to provide much daylight while the amount of source energy increased significantly with respect to horizontal window with the same number of windows. With increasing the number of windows, the amount of source energy decreased in both vertical and horizontal windows. With increasing the number of windows, the amount of source energy decreased in both vertical and horizontal windows, but the differences between DFs varied from 0.2% to 0.7% in the same cases. Overall, none of the models can achieve the least DF in the classroom with 10% WWR with every number of windows, either vertically or horizontally.

According to Table S3, among different classrooms with 20% WWR, only classrooms with 1 and 2 vertical windows can provide a DF above 2%, which is acceptable for reading and writing. Regarding source energy, one vertical window consumed less source energy, therefore, a classroom with 1 vertical window is considered as the optimum one when 20% WWR is applied. With increasing the number of windows, the amount of source energy decline and the amount of source energy in classrooms with horizontal windows is less than that in classrooms with vertical windows when a similar number of windows are applied.

Evaluation of the results presented in Table 7 clarify that when a classroom has 30% WWR, 1 horizontal window provides 3.2% DF, which is ideal; however, other classrooms with more number of horizontal windows cannot achieve a DF above 2% but all classrooms with vertical window can provide a DF above 2%, among them, a classroom with 5 vertical windows is considered as the optimum classroom due to the less source energy respect to the classrooms with 1 to 4 vertical windows. Overall, it can be inferred that 5 vertical windows in a classroom provide the best condition in terms of providing sufficient daylight as well as at least source energy when 30% WWR is applied.

According to Table 8, classrooms with 40% WWR can achieve an acceptable range of DF when 1 or 2 horizontal windows were applied, besides, classrooms with 2 to 5 vertical windows with 40% WWR can reach the acceptable range in terms of DF, but classroom with 1 vertical window and 40%WWR achieve a DF above 5%, which cause exceed heat gain and visual discomfort. Based on the findings of this table, classrooms with 2 vertical windows consumed 403 KW source energy and provided sufficient daylight with 3.15% DF, which is the best classroom with 40% WWR when horizontal windows are applied. In case of using vertical windows in classrooms with 40% WWR, the optimum classroom has 5 vertical windows. The amounts of DF and source energy in this optimum classroom are 3.9% and 402 Kw, respectively.

As shown in Table 9, all classrooms with 50% WWR achieved a DF above the acceptable amount regardless

Table 7. Source energy as well as daylight factor in the classroom with 30% WWR (1-5 windows horizontally and vertically)

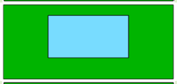
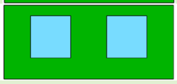
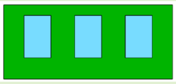
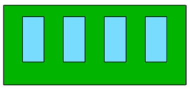
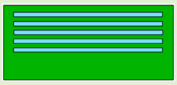
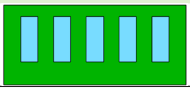
WWR	Figure	No. of windows/Horizontal/Vertical	Total Source Energy	Total Site Energy	DF (%)
30 window area to the external wall		1 horizontal window	389.11	252.33	3.227
		1 vertical window	396.47	259.62	4.029
		2 horizontal windows	384.91	248.02	1.792
		2 vertical windows	400.02	251.82	3.55
		3 horizontal windows	380.66	243.62	0.891
		3 vertical windows	386.96	250.24	3.217
		4 horizontal windows	377.06	239.82	0.505
		4 vertical windows	385.41	248.68	2.918
		5 horizontal windows	371.11	233.43	0.252
		5 vertical windows	383.86	247.12	2.609

Table 8. Source energy as well as daylight factor in the classroom with 40% WWR (1-5 windows horizontally and vertically)

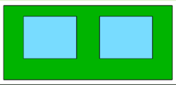
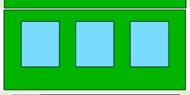
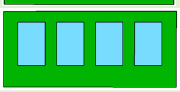
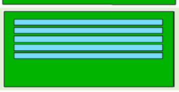
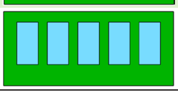
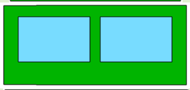
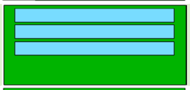
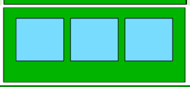
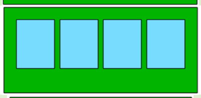
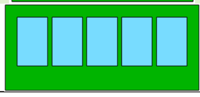
WWR	Figure	No. of windows/Horizontal/Vertical	Total Source Energy	Total Site Energy	DF (%)
40 window area to the external wall		1 horizontal window	408.29	271.08	4.711
		1 vertical window	418.27	280.7	5.404
		2 horizontal windows	403.96	266.75	3.155
		2 vertical windows	407.28	270.11	4.946
		3 horizontal windows	399.47	262.28	1.995
		3 vertical windows	405.63	268.5	4.611
		4 horizontal windows	394.96	257.76	1.203
		4 vertical windows	403.97	266.88	4.221
		5 horizontal windows	390.48	253.23	0.789
		5 vertical windows	402.33	265.28	3.965

Table 9. Source energy as well as daylight factor in the classroom with 50% WWR (1-5 windows horizontally and vertically)

WWR	Figure	No. of windows/Horizontal/Vertical	Total Source Energy	Total Site Energy	DF (%)
50 window area to the external wall		1 horizontal window	427.95	289.93	6.131
		1 vertical window	438.97	300.44	6.766
		2 horizontal windows	423.57	285.67	4.329
		2 vertical windows	426.51	288.56	6.29
		3 horizontal windows	419.11	281.34	3.101
		3 vertical windows	424.82	286.94	6.079
		4 horizontal windows	414.41	276.7	2.146
		4 vertical windows	423.12	285.3	5.688
		5 horizontal windows	409.79	272.15	1.479
		5 vertical windows	421.42	283.68	5.401

of the number of vertical windows but classrooms with 2, 3, and 4 horizontal windows with 50% WWR, could achieve an acceptable DF. Among these classrooms, those with 4 horizontal windows, consumed less source energy, therefore, this classroom is considered as the optimum model.

According to Table S4, only classrooms with 60% WWR and 3, 4, and 5 horizontal windows could reach acceptable daylight in terms of DF. Among these classrooms, those with 5 horizontal windows, had less source energy consumption. It can be concluded that in classrooms with a larger window area, the horizontal window can be more efficient in terms of daylight and less energy consumption.

Discussion

Daylight quality in spaces is significantly affected by window area and its configuration, which supports the results of the present study.

In previous studies by Hanselaer et al. (2007) and Nikpour et al. (2013), daylight optimization reduced energy usage and enhanced thermal and visual comfort (26,27).

The findings of this research demonstrated that classroom with each WWR, one condition provides the least source energy, which can achieve an acceptable daylight factor (DF), which is between 2 and 5%. Several studies have the same assumption with the present study (28-31). None of the classroom models with 10% WWR achieve an acceptable DF. If the classroom has 20% WWR, the optimum model has one vertical window with 376.82 kW.h source energy. In the classroom with 30% WWR, when 5 vertical windows were applied, the amount of source energy of 383 kW.h achieved. Yazhari et al. (2018) suggested a WWR higher than 40% to meet the standard value in terms of daylight in Kerman city(6), using window configuration, and divided window area into 5 vertical windows. The minimum window area can be decreased based on the findings of the present research. Furthermore, Shen et al. (2013) recommended the window-to-wall ratio for Montreal by 30% WWR (32). Kamyab et al. (2023) stated that a model with 20% WWR achieves the least energy consumption for the residential spaces in Yazd city; this result is close to the result of the present research, and differences between the two results can be interpreted due to differences in the size of models and weather data (30). The classroom with 5 vertical windows consumes the least source energy (402 kW.h) among classrooms with 40% WWR. Furthermore, classroom models with 4 horizontal windows are recognized as the optimum model with the least source energy (414 kW.h) among classroom models with 50% WWR. Finally, in the classroom with 60% WWR, the optimum model consumed 429 kW.h source energy when 5 vertical windows were applied.

Conclusion

It can be concluded that creating convenience conditions with minimal energy consumption is related to both heating and cooling loads, as well as providing natural light through the windows. Therefore, WWR and number of windows and their configuration and location in south facing wall have a significant effect on providing a sufficient daylight in the hot and dry climate of Kerman. Considering the weather data and simulation results, it is clear that the cooling loads are more decisive in the amount of energy source. In addition, the results show that models with a lower window-to-wall ratio from 20 to 40%, vertical windows have better performance in providing adequate light and minimal energy consumption, and for classrooms with a WWR between 50 and 60 %, more horizontal windows achieve better performance in terms of daylight and less energy consumption.

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Competing Interests
The authors declare that there are no competing interests—financial, professional, or personal—that could have influenced the work reported in this paper.

Ethical Approval
This study did not involve human or animal subjects. All data used in the simulations were obtained from publicly available sources and standard climatic databases. No ethical approval was required for this research.

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Supplementary files
Supplementary file 1 contains Tables S1-S4.

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