Iranian (Iranica) Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Effect of Fixed Louver Shading Devices on Thermal Efficiency

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P A P E R I N F O

Paper history:
Received 02 October 2021
Accepted in revised form 01 December 2021

Keywords:
Energy consumption
Louver
Optimization
Simulation
Thermal efficiency

A B S T R A C T

Today's energy consumption is one of the most important causes of pollution around the world. Considering the building sector consumes the most energy, it should be seriously considered. In order to provide thermal comfort inside a building, energy is consumed, which can be managed using tools such as louvers that allow solar radiation to pass through the windows while reducing the amount of consumed energy. The goal of this paper is to find the optimal features for shading device of fixed louvers for the east, west, and south facades of the office building at Hakim Sabzevari University in terms of thermal efficiency using parametric analysis. For one year, three rooms on three floors of this building with window louvers at different depths, angles, and distances were thermally simulated with EnergyPlus software and the HoneyBee plugin in addition to the Galapagos plugin for optimization. Based on the optimized samples, it is possible to reduce the thermal energy consumption by 32.34%, 23.71%, and 30.2%, respectively using the ideal louvers on the east, south, and west facades. In terms of thermal efficiency, the distance between the blinds on the south facade and the angle between them on the east and west facades of a window louver are the most significant factors.

doi*: 10.5829/ijee.2021.12.04.08*

INTRODUCTION

According to literature, buildings with residential and office spaces consume 20% to 40% of the total energy [1]. Most of the energy is used for cooling, heating, and lighting in offices and residential buildings. The facade of a building, as the boundary between indoor and outdoor space, has the potential to optimize energy consumption on the one hand and to benefit from renewable natural energy on the other hand [2]. Therefore, it can be said that the performance of a building heavily depends on its shell, especially its windows. For this reason, limiting heating through windows of buildings is ideal [1]. One way of limiting the intensity of solar radiation coming in through windows is to install window overhangs [3]. Although overhangs can prevent the entries of radiation in hot seasons (providing at least 80% of the required shade), they should not block sunlight from entering to a building in cold seasons [4]. Therefore, designers and architects of the building have studied the thermal effects of various overhangs in order to reduce the building's energy consumption. In spite of the development of new design methodologies and production technologies, fixed Shading devices continue to attract considerable research interest. The reason for this can be attributed to some of the advantages of fixed Shading devices, including the simplicity of their design, low maintenance requirements, low cost, and passive usage.[5, 6].

A powerful method for solving the shading device complexities is to use simulations [7]. The number of studies on this method has increased significantly since the 1990s, when these tools were developed [7-10]. These studies mostly focus on energy use [11-16].

Santos et al. [17] conducted a study in Sao Paulo to control how efficiently solar energy is used in buildings. In this study, seven external overhangs were simulated using the EnergyPlus software according to the latitude of the location to determine the efficiency of outdoor overhangs during the year. Eight solar orientations and 12 reference days were considered. After calculating the optimal angle for the shaders, seven overhangs were modeled. Lastly, the evaluations revealed that in general,

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Please cite this article as: H. Bagheri Sabzevar, Z. Erfan, 2021. Effect of Fixed Louver Shading Devices on Thermal Efficiency, Iranian (Iranica) Journal of Energy and Environment, 12(4), pp. 349-357. Doi: 10.5829/ijee.2021.12.04.08

the horizontal overhang was more effective than other overhangs and for the west facade, the vertical overhang on the right side of the window is more effective than on the left.

The effect of physical characteristics of various overhangs on reducing energy consumption was investigated by Sajjadzadeh et al. [18]. They introduced various techniques to optimize energy consumption before and after the construction of a building, focusing on overhang types, dimensions, and depth. In this way, they introduced three classifications for overhangs based on their layout, mobility, and location in the building. In addition, they compared the effects of the overhangs in terms of their location to introduce the types of overhangs in Yazd city's climate. The south and east overhangs were striped during the tests; however, the west and east ones were single. They modeled at various depths. According to the findings, in Yazd, by increasing the depth of the overhang by 90 cm reduced energy consumption and by more than 90 cm increased it. Using a depth of 60 cm on both the east and west facades has the effect of reducing energy consumption as well. No effect was observed in a depth below 60cm.

Krstić-Furundžić et al. [11] studied the effect of fixed external shading devices in horizontal, vertical, and different geometric shapes on the energy performance of office buildings at varying orientations and positions. In the examined office building, heating demands increased from 10% to 39% and cooling demands decreased from 80% to 39% when the Shading device was installed. The authors argue that in order to establish a compromise between energy, design, aesthetics, user comfort, and environmental factors in building design, a comprehensive process of decision-making is required.

For an office building, Farah [16] calculated the potential energy savings of four distinct shading systems: horizontal overhangs, vertical fins, horizontal louvers, and vertical louvers. The results indicated that horizontal louvers were the best shading device type. Additionally, the author found that horizontal shading devices for the east and west facades produced more effective results than vertical shading devices.

A study conducted by Kim et al. [19] examined the design and effects of an exterior shading device to reduce the cooling load on an office building. The authors first calculated the monthly average temperature in the area where the target building was located to design the external shading. There is an overhang installed on top of the building during overheating periods when temperature is over 20 degrees Celsius. Thus, the period of overheating that required shading devices was estimated, and the external overhangs were designed for each direction during that period. Furthermore, the effects of blocking the sun's rays and the percentage of overheating of the shading device were investigated. The cooling loads of the overhangs were then examined. The cooling loads due to solar radiation were evaluated except for internal heat dissipation. Lastly, the daylight performance of the overhangs was evaluated. Results showed a 35.1% reduction in total cooling load. Due to daylight, the useful daylight index has gone up by 2-5%, as well as its range. The brightness of over 2000 lux, which caused visual and thermal discomfort to residents, has decreased.

Unlike the methods mentioned above, Hammad and Abu-Hijleh [14] compared the scenarios in which this system was fixed at certain angles with a Shading device system that moved automatically. According to the results of their study, by using static louvers at an optimum angle, energy savings close to the energy obtained by dynamic louvers were achieved. Based on current investigation, evaluation of dynamic louvers is not a logical choice, as this requires extra cost and effort.

In many cases, fixed overhangs are preferred to movable overhangs due to their simplicity, reliability, low maintenance, and low construction costs. Most of the overhangs used in buildings are fixed models.

The aim of this study is to calculate the optimal louvers depth, angle, and distance between blinds for the south, east, and west facades of the office building of the Hakim Sabzevari University through computer simulation and optimization, in order to achieve the lowest thermal energy consumption. The present research is exploratory and applied.

RESEARCH METHODOLOGY

In order to reduce the thermal energy consumption at the south, east, and west facades, the building energy simulation method was used to determine the most optimal fixed louvers. Building energy simulation is one of the methods of calculating building's energy consumption by taking into account its location and climatic data. Many researchers have used EnergyPlus, a powerful software program built by experts from the University of Illinois and the University of California. In collaboration with other institutions including the Department of Energy of the United States. EnergyPlus is capable of performing detailed analysis of sunlight, heat transfer, and airflow between windows and shutters with varying and complex specifications. Since this program lacks a graphical interface, to input data and to output results, the HoneyBee plugin in Rhino carried out both of these jobs more easily, and the Galapagos plugin performed the optimization. Many researchers have validated EnergyPlus [20, 21] and used Rhino and its plugins [22-24].

The building under study was the office building of Hakim Sabzevari University in Sabzevar (Iran). Because the building stretches to the south and north, unlike other office buildings, most rooms receive strong solar radiation from the east and west during summer. In turn, this significantly increases cooling energy.

In Sabzevar (36°N, 57°E), summers are long, hot, and arid; winters are cold and dry, with mostly clear skies. During the year, the temperature typically varies from -1℃ to 37℃ and is rarely below -6℃ or above 40℃ [25]. The office building of Hakim Sabzevari University has three floors and is located in an open space, which has a U-shaped plan (Figure 1).

During this study, three geographical directions, east, west, and south, were used to uniformly model the louvers features on three floors. The north direction was not considered; because, the building receives negligible solar radiation from the north. Each floor contained three rooms (ground, first, and second floor), in addition to a connecting corridor (because corridors and bedrooms have different temperatures), which was the basis for simulation, since it was similar to most of the rooms in this building. There is an outdoor roof, floor to ground, with windows on one side and adiabatic on the other three. For the simplicity and similarity of the rooms, only three rooms were considered in the calculations (Figure 2). EnergyPlus uses the ideal air load system because it is used in any mechanical system.

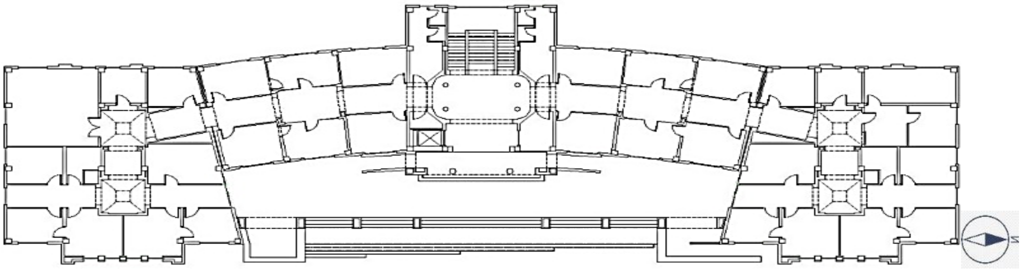


Figure 1. Plan of the office building of Hakim Sabzevari University

Information for simulation input, including the weather file, was generated by Meteonorm software on an hourly basis, while other tables and data, such as activity, clothing, lighting, equipment, air conditioning, and what happens in university office rooms, were entered as primary data.

Materials properties and layers of walls are presented in Tables 1 and 2. In the current situation, the percentage of window openings to the facade level is 22.3%.

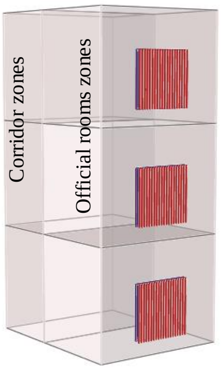


Figure 2. Simulation model

Table 1. windows thermal properties

Property	Value
U-Value (w/m^2-k)	1.25
SHGC	0.76
VT	0.74

Based on the nineteenth book of the National Regulations for Building in Iran, the thermostat heating and cooling set points are 20 °C and 28 °C, respectively. In this research, the aluminum louvers are fixed and unchangeable in all seasons, vertically on the west and east facades, and horizontally on the south facade. As for the variables in overhang design, the depth, distance, and the angle between the louvers are shown in Figures 3 and 4.

Each of the three façades, west, east, and south, has a louver depth. There is a distance between the two louvre blinds of 10 to 35 cm and 5 to 50 cm with a step of 5 cm for west and east lovers and south lover, respectively. The minimum distance between the blades is necessary to ensure the minimum viewing angle and the maximum distance necessary to ensure beauty and performance. Angles of the Louvre blinds are between 0 and 45 degrees for the south and -45 to 45 degrees with a step of 5 degrees for the east and west.

RESULTS AND DISCUSSION

Selected louver of the south facade

For one year, the thermal demand of the three-room complex and corridors with horizontal blinds in 630 modes for the south facade was investigated and optimized. Galapagos' output from the thermal energy optimization included 322 modes. Based on the minimum cooling and heating energy consumption, Table 3 shows the first 10 modes and the last 10 modes of the 322 most optimal overhang modes.

Table 2. Thermal properties of the materials and constructions used in simulation model

	Layers	Thickness (cm)	Thermal conductivity coefficient (W/m.K)	Density (m/v)	Special heat capacity (J/kg.K)
Interior Wall	Stucco	3	0.57	1300	837
	Porotherm	10	0.525	783	790
	Stucco	3	0.57	1300	837
Exterior Wall	Façade brick	10	1	1850	900
	Thermal insulation	5	0.04	80	900
	Porotherm	10	0.525	783	790
	Stucco	3	0.57	1300	837
Roof	Waterproofing	0.3	0.7	2100	836
	cement mortar	2	1.8	2240	900
	Lightweight concrete	5	0.52	1500	900
	Beams and blocks	25	0.71	2100	850
	Stucco	3	0.57	1300	837
Ceiling	Terrazzo	3	2	2400	837
	Cement mortar	2	1.8	2400	837
	Lightweight concrete	5	0.52	1500	900
	Beams and blocks	25	0.71	2100	850
	Stucco	3	0.57	1300	837
Floor	Terrazzo	3	2	2400	837
	Cement mortar	2	1.8	1300	837
	Lightweight	10	0.52	1500	900

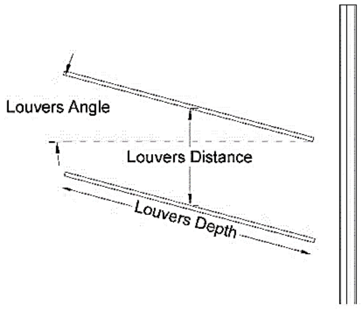
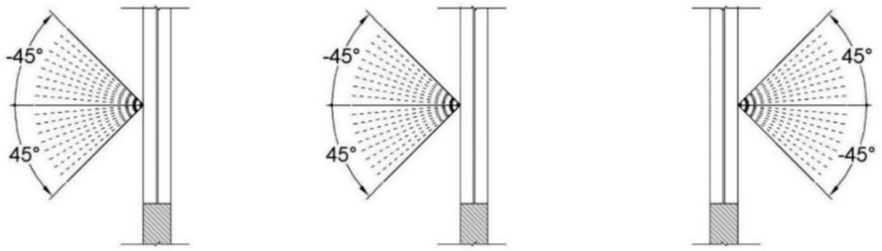


Figure 3. The depth, angle, and distance of the louvres

The most energy-efficient overhang has dimensions of 10 cm between blinds and angle of 35 degrees to the horizon with a depth of 5 cm. According to Table 3, the distance between the louver blinds is the most important factor that increases energy consumption since increasing the distance between the louver blinds from 10 to 20 cm in the first ten cases and from 20 to 45 cm in the last ten cases has increased energy consumption. Therefore, the distance between the blinds has generally increased energy consumption.



a: West Window (Section) **b:** South Window (Section) **C:** East Window (Plan)

Figure 4. The louvers angles of overhang a: West b: South c: East

Table 3. The first 10 modes and the last 10 modes of optimization on the south facade

	Row	**The depth of louver blinds (m)**	**The distance of louver blinds (m)**	**The angle of louver blinds (c)**	**The total energy (kwh/m^2)**
The 10 first modes of optimization	1	0.05	0.10	35	32.4506
	2	0.15	0.20	0	32.4680
	3	0.10	0.15	0	32.4982
	4	0.05	0.10	40	32.5199
	5	0.10	0.25	35	32.5281
	6	0.10	0.25	25	32.5369
	7	0.10	0.25	40	32.5816
	8	0.15	0.25	20	32.6152
	9	0.10	0.25	45	32.6421
	10	0.10	0.25	30	32.6788
	…	…	…	…	…
The 10 last modes of optimization	313	0.05	0.40	20	36.1258
	314	0.05	0.40	30	36.1338
	315	0.20	0.20	30	36.1591
	316	0.05	0.40	10	36.1595
	317	0.05	0.40	35	36.1635
	318	0.25	0.20	35	36.2474
	319	0.20	0.20	35	36.2514
	320	0.05	0.40	45	36.2706
	321	0.20	0.20	40	36.3449
	322	0.05	0.45	35	36.3946

The simulation results for the whole year are shown in Figure 5 to compare the heating and cooling energy consumption of the building in two modes without louver and with optimal louver on the south side. When the louver is placed on the south facade window, the amount of thermal energy consumption can be compared to that without the louver. This can be reduced by 10.08 kwh/m^2 or 23.71%. In addition, Figure 5 shows that the cooling energy consumption in the state without louver increased to 41.48 kwh/m^2 in the louver state, which means that after the installation of the louver, the cooling energy consumption decreased by 13.56 kwh/m^2. The heating energy consumption also increased as well, from 1.05 kwh/m^2 to 4.52 kwh/m^2, an increase of 3.47 kwh/m^2, which is much lower than the decrease in cooling energy consumption.

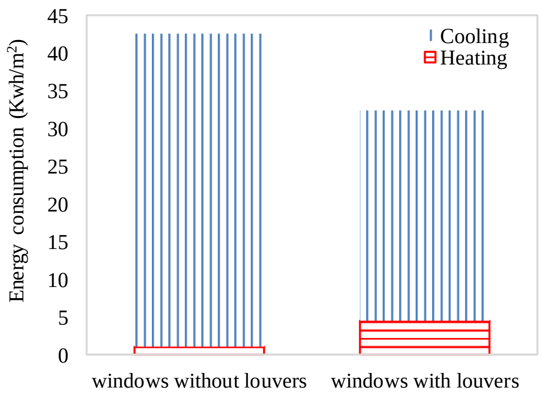


Figure 5. Energy consumption of the complex on the south side in canopy mode and without louvers

Selected louver of the west facade

Based on the simulation of three rooms with vertical blinds in 1197 cases for the west facade, the thermal energy consumption of the complex for an entire year was reviewed and optimized. Galapagos plugin obtained 280 modes out of 1197 simulated louver modes. Table 4 shows the first 10 cases and the last 10 cases; the results show that the most efficient louver is a louver of 35 cm depth, with an angle of 45 degrees to the window surface, and 15 cm spacing between blinds on the west side of the building.

The three factors of louver design alone can affect energy consumption. By decreasing the depth of the blinds, increasing the distance between the blinds, and reducing the angle of the blinds, energy consumption has increased. However, in the first 10 cases, the blade angle

Table 4. The first 10 modes and the last 10 modes of optimization on the west façade

	Row	The depth of louver blinds (m)	The distance of louver blinds (m)	The angle of louver blinds (c)	The total energy (kwh/m^2)
The 10 first modes of optimization	1	0.35	0.15	-45	37.3988
	2	0.25	0.10	-45	37.6745
	3	0.30	0.10	-45	37.7486
	4	0.20	0.10	-45	37.8348
	5	0.35	0.10	-45	37.8667
	6	0.30	0.15	-45	37.9676
	7	0.30	0.10	-40	38.1342
	8	0.35	0.10	-40	38.1433
	9	0.25	0.15	-45	38.2279
	10	0.25	0.10	-40	38.2790
	…	…	…	…	…
The 10 last modes of optimization	271	0.05	0.20	-35	51.1786
	272	0.05	0.25	-30	51.2866
	273	0.20	0.40	-5	51.3308
	274	0.20	0.40	-10	51.3322
	275	0.05	0.20	-30	51.4556
	276	0.05	0.25	-25	51.4744
	277	0.05	0.30	-35	51.5599
	278	0.05	0.30	-30	51.7345
	279	0.05	0.35	-30	52.3428
	280	0.05	0.45	5	52.8035

was the least changed. In terms of the louver design, it could be said that blade angle is the most important variable.

The amount of heating and cooling energy consumption of the building on the west side is shown in Figure 6 for the two modes of operation without louvers and with optimal louvers. Results indicate that the energy consumption in the optimal louver mode is 37.4 kwh/m^2 while without louver, it is 53.61 kwh/m^2. Placement of the louver on the windows of the west facade results in a reduction of 16.21 kwh/m^2 or 30.2% in energy consumption.

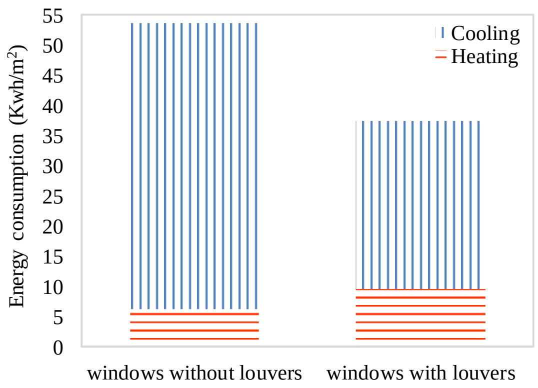


Figure 6. Energy consumption of the complex on the west side in canopy mode and without louvers

Figure 6 also shows an increase in cooling energy consumption in the non-louver mode from 47.33 kwh/m^2 to 27.8 kwh/m^2 in the louver mode. In other words, after installing the louver, the cooling load was decreased significantly and the heating energy consumption was increased by 3.32 kwh/m^2.

Selected louver of the east facade

During one year of simulation with vertical blinds in 1197 modes on the east facade, the thermal load consumption of three rooms was reviewed and optimized. Among the 1197 simulated louver modes, 300 were optimized from the Galapagos. There are 10 cases at the top and 10 cases at the bottom in Table 5. With a 25cm deep louver, 10cm separated blinds, and a 45-degree angle to the horizon surface, a louver with the lowest thermal energy consumption can be found. In general, three factors of louver design influence the amount of energy consumed. By decreasing the depth of the blinds, increasing the

Table 5. The first 10 modes and the last 10 modes of optimization on the east façade

	Row	**The depth of louver blinds (m)**	**The distance of louver blinds (m)**	**The angle of louver blinds (c)**	**The total energy (kwh/m^2)**
The 10 first modes of optimization	1	0.25	0.10	45	37.8754
	2	0.30	0.10	45	37.9736
	3	0.20	0.10	45	38.0184
	4	0.35	0.15	45	38.0969
	5	0.35	0.10	45	38.1158
	6	0.30	0.15	45	38.1772
	7	0.35	0.10	40	38.3120
	8	0.30	0.10	40	38.3176
	9	0.25	0.10	40	38.3831
	10	0.25	0.15	45	38.5122
	…	…	…	…	…
The 10 last modes of optimization	291	0.05	0.15	35	52.2473
	292	0.20	0.40	15	52.3378
	293	0.05	0.15	30	52.6953
	294	0.05	0.20	40	52.7405
	295	0.10	0.35	20	53.0695
	296	0.05	0.15	25	53.0904
	297	0.05	0.20	30	53.3585
	298	0.05	0.20	25	53.6726
	299	0.05	0.30	15	54.6521
	300	0.05	0.30	0	54.7631

distance between the blinds, and reducing the angle of the blinds, the amount of energy consumed has increased. The angle between the blinds has changed the least in the first 10 cases. Therefore, the angle of the blinds plays an important role in the louver's design.

Figure 7 shows the total heating and cooling energy consumption for the three-room complex on the east side of the building for the entire year. It was found that the energy consumption in the optimal louver mode was 37.88 kwh/m^2 and without louver was 55.91 kwh/m^2, and when the louver is fitted on the east facade window, the thermal energy consumption can be reduced compared to the 18.08 kwh/m^2 or 32.34% non-louver modes. Figure 7 also shows that the cooling energy consumption in the non-louver mode has decreased from 49.39 kwh/m^2 to 28.37 kwh/m^2 in the louver mode. In other words, the louver reduced the cooling load considerably and the heating energy consumption did not change considerably with an increase of 3.64 kwh/m^2.

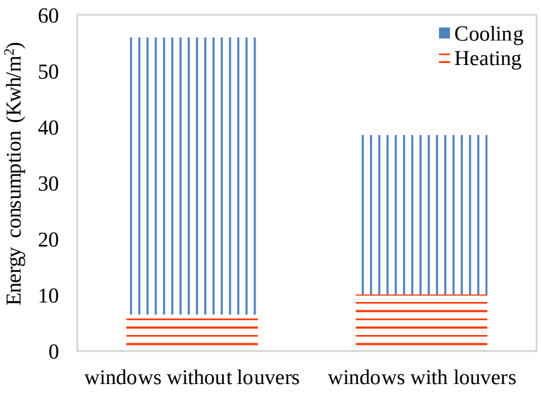


Figure 7. Energy consumption of the complex on the east side in canopy mode and without louvers

CONCLUSION

Louvers are one of the most important controls to protect windows from sunlight, thereby reducing the thermal energy consumption of the building. A louver's depth, angle, and distance from the blinds should be considered when designing a louver. The results showed that a horizontal louver with a depth of 5 cm, an angle of -35 degrees, and a blade distance of 10 cm is the most efficient louver for the south facade in general, and the distance between the blinds plays the most important role for this facade in particular. By increasing the distance between the blinds of the louver, energy consumption has increased. A louver of 35 cm in depth, 45 degree angle, and 15 cm between blinds is the ideal louver on the west facade. On this facade, the angle of the blinds is extremely important in the design of the louver. On the east facade, the most efficient louver design is a 25 cm deep louver which has a 45-degree angle and a 10 cm depth. The angle between the blinds has the most impact on energy consumption on this façade. In all cases, though, the final thermal energy is reduced, but the heating energy has slightly increased. It is caused by the reduction in sunlight from the window, which can be avoided to some extent by changing the angle and movement of the blades. However, installation and maintenance costs will increase.

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Persian Abstract

چکیده

مصرف انرژی امروزه یکی مهم‌ترین علل آلودگی محیط زیست است. لذا ساختمان به عنوان یکی از بخش‌هایی که بیشترین مصرف انرژی را دارد، باید مورد توجه جدی قرارگیرد. فراهم کردن آسایش حرارتی داخل ساختمان، نیازمند مصرف انرژی است که با استفاده از ابزاری مانند سایبان می توان میزان عبوری پرتوهای خورشیدی به داخل ساختمان از طریق پنجره ها را کنترل و مصرف انرژی حرارتی را کاهش داد. این مقاله جهت بدست آوردن سایبان مطلوب جبهه‌های شرقی، غربی و جنوبی ساختمان مرکزی دانشگاه حکیم سبزواری به روش پارامتریک از نظر کارائی حرارتی تمرکز دارد. با استفاده از نرم‌افزار انرژی پلاس و پلاگین هانی‌بی و همچنین پلاگین گالاپاگوس جهت بهینه‌سازی، سه اتاق در سه طبقه این ساختمان با سایبانی با عمق، زاویه و فاصله ی مختلف در طول یک سال شبیه‌سازی حرارتی شد. نمونه های بهینه‌سازی شده نشان داد که با استفاده از سایبان مطلوب می‌توان در هر یک از اتاق‌ های جبهه های شرقی، جنوبی، و غربی تا ۳۲/۳۴ درصد، ۲۳/۷۱ درصد و ۳۰/۲ درصد به ترتیب، مصرف انرژی حرارتی را کاهش داد و مهم‌ترین عامل طراحی سایبان از نظر کارایی حرارتی در جبهه جنوبی، فاصله بین تیغه‌ها و در جبهه‌های شرقی و غربی، زاویه بین آن‌ها است.