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Multi-Objective Optimization to Increase Daylight Efficiency in Rural Buildings Using Passive Systems (Case Study: Vernacular Houses in Kang Village)

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Abstract

Considering optimization to increase the efficiency of daylight in vernacular rural houses by passive systems can mitigate energy consumption in addition to creating suitable conditions for living in those houses. Therefore, this question is raised how effective is the multi-objective optimization to increase the efficiency of daylight in rural buildings by using passive systems. The present study is aimed to evaluate the impact of passive systems via the parameters of building orientation, type of Shading, and Window-to-Wall Ratio (WWR) on vernacular houses in Kang village located in Iran. In this regard, first, 4 houses (2 vernacular houses and 2 non-vernacular houses) located in the village were selected and after comparison, the best house was selected in terms of performance of total energy consumption and lighting load. Then, simulation and algorithm writing were done according to the parameters considered in the research for the selected case sample using Rhino software and Grasshopper plugins, and Ladybug tool. Then, the results were analyzed by Web Design Explorer. Finally, it was found that by using passive systems, the efficiency of daylight can be increased in the vernacular houses of Kang Village at a much lower cost than using active systems, and as a result, energy consumption is mitigated, which this will retain the environmental conditions.

Keywords: Daylight; Passive systems; Increase efficiency; Rural houses

1. Introduction

Iran is one of the countries with the potential of renewable energy sources in the form of solar energy and natural light. Different solutions for using renewable energies such as photovoltaic cells and solar thermal hybrid solutions have also been discussed (Al-Douri et al., 2019). But it is worth mentioning that the most energy consumption in buildings is related to the use of active systems to maintain indoor comfort, and an optimal balance should be found between the initial investment and energy savings during the life cycle of the building (Rodrigues & Freire, 2017). However, passive design strategies not only help to improve indoor comfort conditions, but also help to increase energy efficiency in buildings and reduce energy consumption (Rodriguez-Ubinas et al., 2014). It should also be considered that to create a healthy and dynamic environment, it is necessary to achieve buildings with efficient energy and high-quality natural light (Maleki & Dehghan, 2020). Indeed, daylight includes direct and indirect rays of sunlight shining on the earth during the day. In addition to being required by the environment, this light is also needed by humans, because it brings brightness and vision. In addition, daylight is required for the natural lighting of buildings, and the level of visibility of users in any space depends on the presence of sufficient light in that space. However, more awareness of daylight in architecture and urban design, beyond aesthetic values and visual comfort, may result in higher-quality of working and living environments (Wirz-Justice et al., 2021). However, in the architecture debate, more attention has been paid to the way of distributing daylight in the environment and creating visual comfort for the residents, while today the issue of daylight is considered beyond it, as various researches demonstrated that has a great impact on reducing energy consumption in buildings (Bellia et al., 2020; Kaminska & Ożadowicz, 2018; Lakhdari et al., 2021). Thus, it is possible to prevent the excessive production of CO^2 and ultimately prevent damage to nature and human beings. In general, the use of light in built environments has comfort, behavioral, economic and environmental consequences (Knoop et al., 2020). Indeed, a suitable architectural design can reduce energy consumption in the electric lighting sector (Acosta et al., 2015), because statistics have shown that electric lighting includes between 15 and 30 percent of the total energy consumption in buildings (Ryckaert et al., 2010).

However, when designing buildings and namely when using passive systems, criteria related to the amount of light in the building's interior should be taken into attention. Indeed, daylight criteria serve as a useful tool to quantify the potential for natural light in architectural space

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as well as energy savings via the appropriate design of windows, atriums, and skylights (Acosta et al., 2019). One of the criteria is the daylight autonomy (DA) criterion is a measure of how often a minimum work plane illuminance threshold of the work plane (often 300 lux) can be maintained only by daylight. This criterion is defined for one year and as a percentage of people's attendance time. Various studies have used this criterion in their research (Mangkuto et al., 2016; Vanhoutteghem et al., 2015). Another criterion is useful daylight illuminance (UDI), which was developed by Nabil et al (Nabil & Mardaljevic, 2005). This measure shows the distribution of lighting along the work plane, within the range that is considered useful and usable by the residents of that environment. Indeed, UDI enables us to determine an efficient architectural design to use daylight (Al-Obaidi et al., 2015). UDI can be divided based on three ranges of illuminance 0-100 lux, 100-2000 lux, and over 2000 lux. Useful lighting is in the range of 100 lux to 2000 lux, if the illuminance is within 0-100 lux needs for supplementary light, and in the range of above 2000 lux, glaring is occurred for the occupants and in both conditions causes visual discomfort among the residents. In fact, UDI has shown its practical application for window design (Berardi & Anaraki, 2015).

Using daylight can be an effective strategy to improve energy efficiency in buildings, because supplementary lighting accounts for 40% of a building's energy consumption (Alrubaih et al., 2013). Thus, it is possible to prevent energy dissipation and environmental damage, if we mitigate the ratio of using electric lighting (Yun et al., 2014). Increasing the exploitation of daylight reduces the need to use supplementary light during the day for indoor environments, and it is possible to reduce the use of supplementary lighting systems as long as possible and until it is day. As a result, this can reduce the electricity consumption of the building. However, despite extensive research on daylight, there is not enough data to justify a definitive statement on daylight design criteria (Tregenza & Mardaljevic, 2018).

Daylight also brings heat into the building, so the amount of light entering the building should be controlled according to various conditions such as the climatic conditions of the area, WWR, building orientation, and other parameters. This is especially considerable in rural houses without electronic and mechanical systems for heating and cooling, because increasing the use of daylight thermal energy mitigates the use of heating systems, especially in cold seasons. Indeed, passive systems to use daylight in the indoor of buildings have common goals with cooling systems and heat generating systems in interior spaces (decreasing thermal energy waste and reducing energy consumption). Many studies have shown that the use of passive systems is effective on increasing the use of daylight and increasing energy efficiency (Altenberg Vaz & Inanici, 2021), such as using the building orientation (Chi et al., 2019), WWR (Jareemit & Canyookt, 2021) and using the type of window (Graiz & Al Azhari, 2019), which account for about 60% of heat loss via the conduction, transmission and radiation of these windows (Jelle et al., 2012). The present study evaluates the increase of the efficiency of daylight, but the same increase in daylight efficiency will lead to an increase in the efficiency of thermal energy and a decrease in energy consumption.

In fact, the current study is based on the assumption that considering the high number of individuals who live in residential houses located in villages in Iran, there is a great potential for the multi-objective optimization to increase daylight efficiency in rural buildings using passive systems. In addition to increasing the daylight efficiency and optimizing the energy consumption of rural houses, the final result can be a considerable reduction in energy consumption in Iran, which in turn reduces the production of environmental pollutants and helps to protect the environment. In fact, the current study considers rural houses as its case study according to its mentioned potentials, while most of researches on optimizing energy consumption and daylight have focused on urban residential buildings (Delgarm et al., 2018; Kohansal et al., 2021).

2. Research background

In the following section, the research background is evaluated in the form of two different research fields (the field of building energy efficiency via passive systems and the field of daylight and energy efficiency), as related to the current research. In the current research, increasing the efficiency of daylight can ultimately mitigate energy consumption, and this reduces the environment damage.

2.1 The field of building energy efficiency via passive systems

In recent years, many researches have been conducted in the field of energy efficiency of buildings in different climates via passive systems (Honarvar et al., 2022; Lee et al., 2020; Rivera et al., 2021; Wang et al., 2020; Yu et al., 2020), passive design strategies offer the potential to improve energy efficiency in buildings (Alagbe et al., 2019). For example, in a study conducted in the United Arab Emirates (Friess & Rakhshan, 2017), the effectiveness of building passive envelop measures that reduce energy consumption, which include specific building envelope measures as retrofit, including radiative, convective and conductive heat transfer through walls, windows, roof, as well as energy-efficient natural ventilation techniques, the results of which have indicated significant changes in terms of energy optimization. Another study conducted in China (Chi et al., 2021), a new passive double- heating and double-cooling system was evaluated with the aim of improving the energy efficiency of the building. The proposed passive system included a passive double-heating system (solar heating and water-to-air heating) and a passive double-cooling system (vegetation transpiration cooling and water-to-air cooling). In addition, an independent residential building was selected as the study building, to evaluate its energy efficiency by using the proposed passive system. The result indicated that due to the passive system with double-heating and cooling functions, the indoor thermal comfort in the building can be significantly improved compared to the base case. Another research titled (Multi-objective optimization of passive energy efficiency measures for net zero energy building in Morocco) (Abdou et al., 2021), aimed to evaluate the possibility of achieving a net zero energy building by a combination of architectural energy efficiency practices and renewable energy for the production of hot water and electricity in Morocco. Parameters such as building orientation, windows type and Window-to-Wall Ratio (WWR), wall and roof insulation, have been considered and allowed a compromise between the building life cycle cost, energy saving, and thermal comfort through optimizing the mentioned parameters. It was found that by using these passive systems, energy, heating, and cooling load can be saved by 21, 28 and 40%, respectively. Researches conducted in this field have all indicated the great impact of passive systems on optimizing energy consumption, which shows the high value of researches in this field.

2.2 The field of using daylight and energy efficiency

Supplementary lighting accounts for a large share of electricity consumption in buildings in the world. For example, in Iran, 25% of electricity consumption in office buildings produces artificial lighting (Mahdavinejad et al., 2012). Thus, it is important to develop methods to minimize electricity consumption for lighting via the best design decisions (Pilechiha et al., 2020a). To achieve this goal, the optimal use of natural daylight is of great importance.

In rural houses and especially in rural houses with a mountainous climate, increasing the efficiency of daylight is of great importance, because at the same time considering the different characteristics of windows to increase daylight efficiency, the issue of energy waste through the same windows should also be considered. For this reason, it is important to use multi-objective analysis for daylight optimization, which examines several variables simultaneously and also considers the impact of those variables on each other at the same time. Thus, the optimization of daylight in rural houses, especially in mountainous climate, includes creating a balance between three main goals linked to each other: increase energy efficiency through daylight, at the same time as reducing energy waste, and at the same time creating visual comfort for occupants.

In general, various researches have been carried out to optimize daylight with different goals, at least one of which is optimizing energy consumption (Chen et al., 2020), create thermal comfort (Chi et al., 2020), and visual comfort (Refaat, 2018). But most of researches in this field is on residential buildings (Albatayneh et al., 2021; Li et al., 2021; Varuna Lakshmi & Gunarani, 2019), office buildings (Jin & Overend, 2017; Maltais & Gosselin, 2017; Montaser Koohsari & Heidari, 2021) and educational buildings (Lakhdari et al., 2021), located in cities. However, rural houses account for a significant part of the world's residents. Indeed, various researches have been conducted in the field of daylight optimization in rural houses. For example, Chi, in a research in China, "Investigation of optimal Window-to-Wall Ratio based on changes in building orientation for traditional houses" (Chi et al., 2020), considered the parameters of building orientation and WWR. Considering that the ratio of glazing and opaque areas on building facade has a great effect on visual comfort, thermal comfort, and energy consumption, therefore it is necessary to consider the WWR parameter for rural houses.

In Iran, where nearly 30% of the occupants live in rural houses, it is necessary to conduct research to optimize daylight with various goals such as energy optimization, creating thermal and visual comfort. Some of researches conducted on this field and in rural houses located in Iran are presented in Table 1.

Table 1
Some of researches in the field of daylight efficiency, natural ventilation, energy consumption, thermal comfort, building life cycle, and visual comfort (in non-rural and rural buildings**)**

	Researches conducted to optimize daylight in non-rural buildings				**Factors considered in the evaluation**					
	Authors and year	**Buildi ng type**	**Research focus**	**Investigated parameters**	**Day-light**	**Natural ventilati-on**	**Building energy consumption**	**Thermal comfort**	**Buildi-ng life cycle**	**Visual comfort**
1	(Fathi & Kavoosi, 2021)	Office	Exploitation of daylight and energy consumption optimization	WWR	+		+			
2	(Maleki & Dehghan, 2021)	Office	Exploitation of daylight and energy consumption optimization and create visual comfort	WWR, Window shape, the location of window in each façade by considering the window threshold height	+		+			+

3	(Montaser Koohsari & Heidari, 2021)	Office	The exploitation of daylight, create thermal and visual comfort	WWR, Width to height ratio (WHR), sill level	+		+	+
4	(Pilechiha et al., 2020b)	Office	Exploitation of daylight and energy consumption optimization	WWR, Window geometry, window configuration	+	+		+
5	(Maleki & Dehghan, 2020)	Reside ntial	Exploitation of daylight and energy consumption optimization	WWR, Window orientation	+	+		
6	(Nasrollahi & Shokry, 2020)	Educati onal	Exploitation of daylight and energy consumption optimization and create visual comfort	The location and dimensions of windows, materials reflectivity، Levels layout and space fit, WWR	+	+		+
7	(Shaeri et al., 2019)	Office	Exploitation of daylight and energy consumption optimization	WWR	+	+		
8	(Zomorodian & Tahsildoost, 2017)	Educati onal	The optimization of daylight and create thermal and visual comfort	WWR ،Glaze and shade of window ، orientation ، U-value of a window	+		+	+
9	(Khakian et al., 2020)	Rural dwellin g	Energy consumption optimization, exploitation of daylight	Building orientation, WWR, glazing, Shading systems, insulation	+	+		
10	(Khakian et al., 2020)	Rural dwellin g	Energy consumption optimization, exploitation of daylight	Building orientation, WWR, glazing, Shading systems, insulation	+	+		

2.3 The field of daylight effects in indigenous and non-indigenous houses

The evaluation of the impact of daylight has been evaluated in different fields, such as the impact of daylight on visual comfort (Cajochen et al., 2019; Fasi & Budaiwi, 2015), the health of occupants (Nagare et al., 2021; Robertson et al., 2015), energy efficiency (Bahdad et al., 2021; Kaminska & Ożadowicz, 2018) and thermal comfort (Ahmad et al., 2022; Ebrahimi-Moghadam et al., 2020). One of the most fundamental problems related to the use of daylight in indigenous and non-indigenous houses is creating a balance between the efficiency of daylight illumination and the heating caused by it. In tropical regions, excessive sunlight has become a common problem in providing sufficient daylight, as it can lead to overheating (Fitriaty et al., 2019). Therefore, increasing daylight efficiency may lead to a decrease in thermal efficiency if the daylighting strategies employed are not appropriate (Gago et al., 2015). Also, in cold regions, excessive radiation and intensity of sunlight, although helps to create heating in the cold seasons of the year, but the same can lead to excessive heat in the indoor space in the hot seasons of the year (Zhang et al., 2017). This is more evident especially in indigenous rural houses that usually lack active systems for heating and cooling.

However, several studies have also shown that it is possible to increase the efficiency and performance of daylight by using strategies, such as using optical shelves (Lim & Heng, 2016), optical tubes (Chirarattananon et al., 2000), shadowing (Konstantoglou & Tsangrassoulis, 2016), and internal reflection (Mangkuto et al., 2016). It should be noted that the use of each strategy should be done according to the place under investigation; in addition, the use of several strategies, at the same time, can also be uneconomical. The applied research process in the present study is shown in Figure 1.

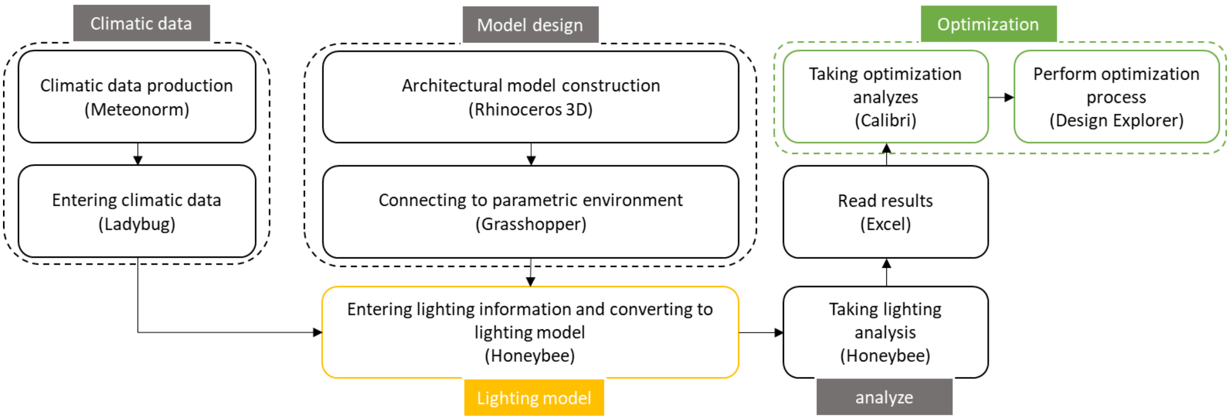

Fig. 1. Applied process of research

3. Research Questions

1. How is the optimization of daylight in the buildings of Kang village by using passive systems?
2. How is the effect of passive systems on increasing daylight efficiency in rural buildings?

4. Research Methodology

The data collection method in the present study is library and field, and in this research, the simulation method based on computer modeling with software analysis is used. The present study examines the daylight optimization using passive systems in rural residential houses located in Kang village in Iran. A detailed description of the adopted procedure is given below.

4.1 Study area

One of the important factors in the architectural design process is site analysis (Azizi et al., 2022). Kang village, at longitude of 59 °13 ‘and latitude of 36 °19, and a height of about 1700 meters above sea level, is located in Razavi Khorasan province of Iran. As shown in Figure 2, this village has a stepped architecture and the roofs of the lower buildings are used as the courtyards of the upper buildings. In the hot seasons, Kang village has a moderate climate, which is due to the presence of high mountains in the area, as well as many trees and cool winds. However, in the cold seasons, it has a cold mountain climate for the same reasons.

Fig. 2. Kang village, Iran

4.2 Data collection method

In the present study, the geographical features of the Kang village area were classified and determined by three methods. The first method is library and the review of books prepared by the Housing Foundation of the Islamic Republic of Iran (Kang Village guide Plan), the second method is through field investigation of the studied area and data collection, and the third method is through survey of villagers. Finally, the received information was classified and used.

4.3 Simulation instrument

In this study, Rhino3D software and Energy Plus engine have been used to perform the simulation process. One of the essential features of Energy Plus is that this software can be used as an analysis and simulation engine in some types of software such as Design Builder, Rhino3D. In the current research, due to the need to use the Ladybug plugin, Rhino software was used.

4.4 Validation

Due to the limitations in the present study, to validate the results obtained by the Energy Plus and the Ladybug tool plugin, other studies have been used that have verified the results and outputs of the software used in the present study. Many researchers have confirmed the validity of the results of the EnergyPlus engine in their papers (Ahmadnejad et al., 2022; Blanco et al., 2016; Honarvar et al., 2022; Shehadi, 2018; Zhuang et al., 2010), while they have also verified the Honeybee and Ladybug plugins in their articles researches (Bakmohammadi & Noorzai, 2020). However, to be ensured of the findings of the current research, we referred to the study done by Reza Khakian and his colleagues (Khakian et al., 2020). In addition to the similarity of the selected location in the research, which is in a village similar to Kang village called Palengan village in Kurdistan (Iran), the given study has pursued relatively similar goals with the current research. The mentioned study was aimed to evaluate the energy performance of two-story residential buildings located in the village by examining the effect of passive systems. This research has also used the Energy Plus engine to perform its simulation process, and its validation indicates that this software provides accurate results.

4.5 Research procedure

4.5.1 First phase (selecting a case sample)

In the first phase, 4 residential houses were selected through field visits, and then they were compared in terms of the amount of energy waste (with the Grass Hopper plugin in the Rhino software and the Lady Bug tool plugin), to determine which of the houses have the best possible condition in terms of the optimal performance of the total load of energy consumption and lighting load. These houses included two houses with the structure of vernacular rural houses and two houses with the structure of non-vernacular house building (Figure 3). The reason for selecting 2 vernacular houses and 2 non-vernacular houses is that in addition to the presence of vernacular houses, many houses in Kang village are built with non-vernacular structures, so it is decided first to compare the amount of energy consumption as well as the lighting load and then the best house in terms of performance of the mentioned items were selected as the main case sample in the current research. The plan of each house is shown in Figure 4. Due to having a more accurate comparison, we attempted to select these houses almost close to each other in terms of size, building orientation, heating, cooling, and lighting systems. Besides, it should be stated that the selected buildings all have a lower floor, which is an old and unused barn. The characteristics of each of these houses are also presented in Table 2.

Fig. 3. The exterior view of 4 houses from Kang village, to compare with each other in terms of cooling and heating load and lighting

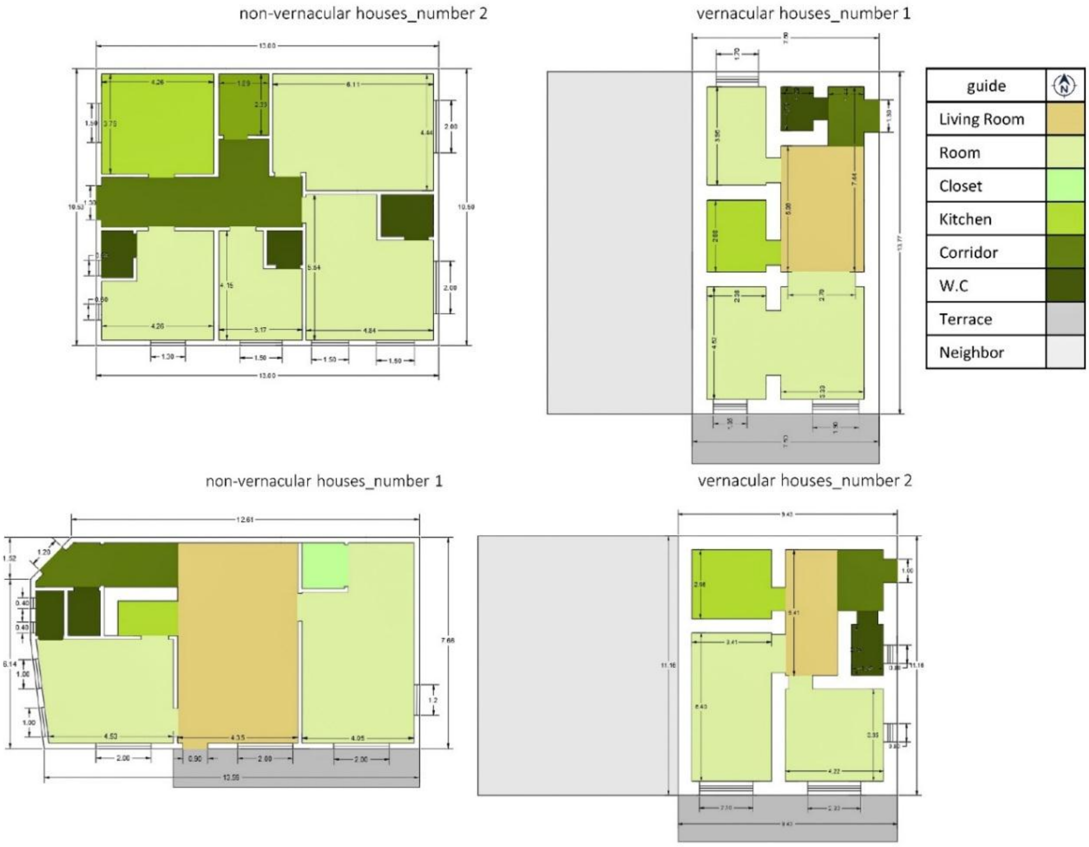

Fig. 4. Plans of two current vernacular houses and two non-vernacular houses in Kang village

Table 2
Features of mentioned houses (comparison of houses with vernacular house building structure and houses with non-vernacular house building structure)

Residential houses	Area (m^2)	Building elongation	Walls materials	Building structure	Building coverage	Walls thickness (m^2)	Neighbors	Type and material of windows	Heating, cooling system, and ventilation	Insulation	Lighting system
Vernacular house 1	**105**	North-south	Stone	Stone	Thatched	**0.6**	In the west	Wooden-simple	-	-	Urban power
Vernacular house 2	**103**	North-south	Stone	Stone	Thatched	**0.6**	In the west	Wooden-simple	-	-	Urban power
Non-vernacular house 1	**137**	East-west	Brick	Steel structure	Brick	**0.2**	-	Metal-simple	-	-	Urban power
Non-vernacular house 2	**105**	East-west	Brick	Steel structure	Brick	**0.2**	-	Metal-simple	-	-	Urban power

4.5.2 The second phase (simulation and analysis of consumption load)

The simulation process of these 4 selected houses was performed using the Grasshopper plugin in the Rhino software. Fnally, the amount of cooling and heating load as well as the lighting load of each house according to the situation Available and measured for one year using the Ladybug plugin in the Grasshopper (12 months).

4.5.3 Third phase (simulation to evaluate the level of lighting)

At this phase, based on their influence of each variable of the determined parameters on the other and as a result of its effect on the total lighting load of the building, the algorithm was re-written for the case sample selected (which is determined in the second phase) was done by Rhino software and Grass Hopper simulator and Lady Bug tool plugin to analyze the mutual effects of each variable on the other and to determine the optimal model with the aim of increasing daylight efficiency for the vernacular residential building.
In general, 3 parameters were evaluated, which include building orientation, shading depth, and WWR. The reason for selecting these three parameters is because of their impact on the goals of the research. The orientation parameter of the building was considered at the angles of (70, 80, 90, 100, and 110) degrees, because according to the route of the sun in the study area, these geographical directions have a greater effect on the amount of light transmitted than other angles. As a result, only these angles are considered in order to facilitate the research. For the shading depth parameter, the depths (0.15, 0.20, 0.25, 0.30, 0.35) in m^2 were also considered, because according to the issue of the economic status of the villagers, the fixed Shading can be the best option. In addition, proper shadings have a great impact on environmental sustainability and also reduce carbon emissions (Razazi et al., 2022). For the WWR parameter, the variables (10%, 20%, 30%, 40%, 50%, and 60%) were used. It is worth noting that for the WWR parameter, even though it is not possible to use the variables (10% and 60%), especially in rural residential houses in cold climates, however, because the aim of the current study was to achieve the best possible condition in terms of increasing the efficiency of daylight, these percentages were also considered. The parameters considered to achieve increasing the efficiency of daylight are shown in Table 3.

Table 3
Parameters to achieve the goal of increasing daylight efficiency

	Parameter name	Variables					
1	WWR (percent)	10	20	30	40	50	60
2	Building rotation angle (degree)	70	80	90	100	110	-
3	Shading depth (m^2)	0.15	0.2	0.25	0.3	0.35	-

In this section, after producing the architectural model and converting it into an energy model (in the Grass Hopper environment), the openings were determined according to the existing situation. Next, based on the neighbors, it was determined which walls should be defined as adiabatic, the building materials were defined, and the variables of each parameter along with their characteristics (the parameters of building orientation, Shading depth, and WWR) were determined. Then, the settings related to the selected optimization type (Multi-Objective Optimization) were determined for this algorithm, and the weather file (in epw file format) was placed in the path of the algorithm. Besides, it should be mentioned that active heating, cooling, and ventilation systems were not considered for the house in this study, because the present study aimed to optimize daylight exploitation using passive systems in the vernacular houses of Kang village in the best way.

4.5.4 The fourth phase (Analysis using Design Explorer)

After performing the algorithm writing process and determining the given features, the final file in format (data.csv) was generated. Then this file was imported into the Web Design Explorer environment. Then, based on the variables of each parameter and the influence of them on each other, the best modes to find the most optimized state was generated in terms of increasing daylight exploitation efficiency in the indoor of rural residential houses (Figure 5).

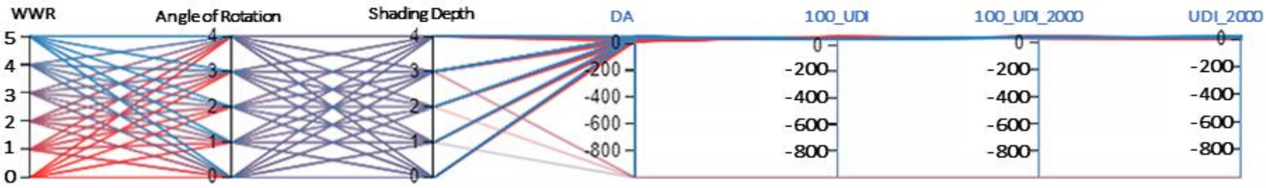

Fig. 5. The modes produced by Web Design Explorer to obtain the lighting percentages of vernacular house No. 2 using different modes of the determined variables.

Each of these modes contains a collection, which include certain data. In fact, each collection shows a specific value for each of the determined parameters, which finally shows the lighting load for each set (Figure 6). This means that if this data set of variables is used for the design of the given building, the lighting load will eventually reach a certain value.

Fig. 6. Specified values for one of the proposed modes for optimal daylight design in Design Explorer

4.5.5 Determine intervals (DA, 100-UDI, 100-UDI-2000, UDI-2000)

To analyze and evaluate the lighting load, there are 4 options (DA, 100-UDI, 100-UDI-2000, UDI-2000) in Design Explorer, by changing each of them, you can narrow down the possible modes that can be used for daylight optimization in the given vernacular building, so that the desired answer can be achieved. As a result, considering that the current study aims to achieve the best possible mode in terms of increasing the efficiency of daylight, the value (DA) was considered in the highest possible states, because in the percentages of time that the space is used, the space has illuminance over 300 lux. However, in regarding the options related to (UDI), the intervals of the 100-UDI and 2000-UDI options were considered as minimum as possible to avoid the possibility of using supplementary light during the day or causing glaring and, as a result, reducing visual comfort of residents. On the other hand, the range 100-UDI-2000, which is the most appropriate mode, was considered the best possible value so as to provide the maximum use of useful daylight for the indoor of the house. As a result, in this research, DA is in the range 40-50, 100-UDI between 40-50, 100-UDI-2000 between 43-47, and UDI-2000 between 10-12. The modes produced by Web Design Explorer to obtain the lighting percentages of vernacular house No. 2 using the specified lighting intervals are presented in Figure 7.

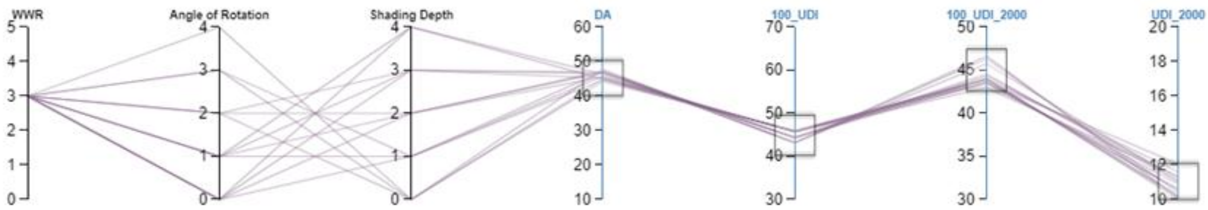

Fig. 7. Modes produced by Web Design Explorer to obtain the lighting percentages of vernacular house No. 2 using lighting ranges

5. Results and discussion

Based on the division of the stages of the research method, in this section, first, the results and discussion related to the simulation and load analysis stage are mentioned separately, and then the results of the next stage are evaluated and discussed.

5.1 Simulation and load analysis

After simulating the 4 houses selected as case samples with the Grass Hopper plugin in the Rhino software, the amount of cooling and heating load and lighting load of each house was measured based on the existing situation for one year (12 months) using the Lady Bug plugin in the Grass Hopper environment. The results of the measurement are evaluated in the followings.

5.1.1 Vernacular house 1

After taking the plan and features of vernacular house 1 and designing it in the Grass Hopper environment, the amount of cooling and heating load as well as the lighting load for each month of the year was analyzed using the Ladybug plugin separately. Finally the total load of energy consumption the building was calculated (Table 4).

Table 4
Normalized energy load of the floor, for vernacular house 1 for 12 months of the year based on kWh/m^2

Month	Cooling	Heating	Lighting	Total Load (vernacular house 1)
1	0.0	20.48	3.06	23.5
2	0.0	14.54	2.71	17.3
3	0.0	7.6	3.06	10.7
4	1.88	2.1	2.76	6.7
5	8.7	0.0	3.25	11.9
6	17.9	0.0	2.54	20.4
7	19.7	0.0	2.21	21.9
8	16.7	0.0	2.11	18.8
9	8.9	0.1	3.12	12.2
10	0.0	1.7	2.32	4.0
11	0.0	11.7	2.62	14.3
12	0.0	18.2	2.12	20.3
Total Load				**181.9**

5.1.2 Vernacular house 2

Like the case sample of vernacular house 1, after performing the simulation steps, the amount of cooling and heating load as well as the lighting load was analyzed separately for each month of the year. Fnally, the total load of the building's energy consumption was calculated (Table 5).

According to the results presented in Table 5 and also by calculating the total load (for one year), it was observed that vernacular house 2 compared to vernacular house 1 outperforms by 23.6 percent in terms of the total energy consumption load during one year.

Table 5
Normalized energy load of the floor for vernacular house 2 for 12 months of the year based on kWh/m^2

Month	Cooling	Heating	Lighting	Total Load (vernacular house 2)
1	0.0	14.28	2.06	16.3
2	0.0	10.16	2.22	12.4
3	0.0	5.3	1.06	6.3
4	1.23	2.0	2.43	5.6
5	6.5	0.0	2.32	8.8
6	13.4	0.0	2.12	15.6
7	14.9	0.0	2.01	16.9
8	12.8	0.0	2.26	15.0
9	7.0	0.1	3.55	10.7
10	1.1	1.7	2.86	5.6
11	0.0	7.8	2.13	9.9
12	0.0	13.2	2.60	15.8
Total Load				**139.0**
Percentage of improve (%)				**23.6**

Table 6
Normalized energy load of floor for non-vernacular house 1 for 12 months of the year based on kWh/m^2

Month	Cooling	Heating	Lighting	Total Load (Non-vernacular house 1)
1	0.0	31.34	2.90	34.2
2	0.0	23.98	2.61	26.6
3	0.0	14.8	2.90	17.7
4	3.03	6.9	2.35	12.3
5	6.7	2.6	2.62	11.9
6	15.9	0.0	2.52	18.4
7	17.9	0.0	2.26	20.1
8	13.1	0.0	2.57	15.7
9	5.6	0.1	3.52	9.2
10	0.0	4.0	2.88	6.9
11	0.0	18.5	2.82	21.3
12	0.0	28.8	2.94	31.7
Total Load				**226.1**
Percentage of improve (%)				**-24.3**

5.1.3 Non-vernacular house 1

The non-vernacular house 1 was analyzed separately after modeling, analyzing cooling and heating load as well as its lighting load for each month of the year, and the total energy consumption of the building was calculated (Table 6).
As shown in the results presented in Table 6 and also by calculating the total load (for one year), it was observed that the non-vernacular 1 compared to the vernacular house 1 performs poorly by 24.3 percent in terms of the total load of energy consumption during one year.

5.1.4 Non-vernacular house 2

Finally, the non-vernacular house 2 was modeled and evaluated separately in terms of cooling and heating load as well as lighting load for each month of the year. Finally, the total load of the building's energy consumption is calculated (Table 7).

Table 7
Normalized floor energy load for non- vernacular house 2 for 12 months of the year based on kWh/m^2

Month	Cooling	Heating	Lighting	Total Load (Non- vernacular house 2)
1	0.0	23.43	2.26	25.7
2	0.0	16.90	3.55	20.5
3	0.0	9.1	2.86	11.9
4	1.03	4.0	2.35	7.4
5	5.1	0.0	2.54	7.6
6	15.1	0.0	2.21	17.3
7	16.2	0.0	2.11	18.3
8	11.1	0.0	3.12	14.3
9	4.6	0.1	2.32	7.0
10	0.0	3.0	2.43	5.4
11	0.0	13.8	2.32	16.1
12	0.0	21.7	2.94	24.6
Total Load				**176.1**
Percentage of improve (%)				**3.2**

According to the results presented in Table 7 and also by calculating the total load (for one year), it was observed that the non-vernacular house 2 compared to the vernacular house 1 outperforms for one year by 3.2% in terms of the total load of energy consumption.
By comparing 4 houses (two vernacular houses and two non- vernacular houses) in Kang village, it was observed that vernacular house 2, non-vernacular house 2, vernacular house 1Finally non- vernacular house 1 have the lowest amount of energy consumption load during one year. The comparison of the total load of energy consumption for each month with other months for each house is presented in Figure 8. Accordingly, in general, it can be said that the vernacular houses of Kang village perform better in terms of total energy consumption compared to the non-vernacular houses built in this village, which have the characteristics of non-vernacular house construction and don’t follow the vernacular house construction.

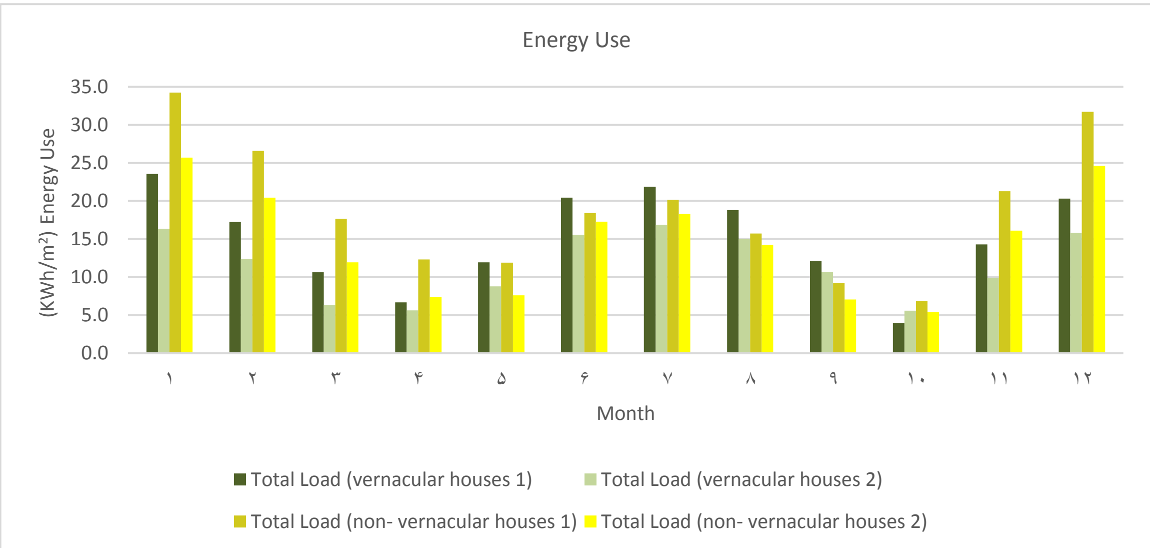

Fig. 8. Comparison of energy consumption during one year and for 4 houses (two vernacular houses and two non- vernacular houses), in Kang village

According to the results obtained, the best house in terms of the energy load optimization compared to other houses (vernacular house 2), as a case sample for carrying out a multi-objective optimization process to increase the efficiency of daylight in rural buildings was selected using passive systems in Kang village.

5.1.5 Analysis using design explorer

After selecting the case sample and performing the simulation steps to evaluate the lighting, web design Explorer environment was used to analyze the results. Several studies have used design Explorer for data analysis, such as (Khidmat et al., 2021; Tabadkani et al., 2018), which indicates the accurate results of this web-based software. One of the reasons for selecting the Web Design Explorer environment is that it does not determine the best option for the designer, and only displays the possible modes, and it is the designer who selects the best mode according to the conditions and type of design. As a result, the designer can specify the desired and expected lighting load according to the conditions, so that the Design Explorer limits the options according to it. Considering all these conditions, the designer can freely choose the overlapping type of parameter variables and he can make changes in his design type based on the different conditions of the project and is not limited to choosing one option. After uploading the file with (data.csv) format in Design Explorer, according to the variables of each parameter, 151 possible modes were generated (Figure 7). In the following, according to the selected range for the variables in the Web Design Explorer environment (DA, 100-UDI, 100-UDI-2000, UDI-2000), a total of 14 different modes were determined, the specifications of each of which are shown in Table 8.

Table 8
Modes determined by Design Explorer, according to the lighting ranges determined for (DA, 100-UDI, 100-UDI-2000, UDI-2000)

Model number	WWR (%)	Building rotation angle (degree)	Shading Depth (m^2)	DA (%)	UDI: (100-UDI) (%)	UDI: (100-UDI-2000) (%)	UDI: (UDI-2000) (%)
1	**40**	**90**	**0.15**	**47.69**	**43.15**	**45.75**	**11.07**
2	40	100	0.15	44.97	45.85	43.5	10.56
3	40	110	0.15	44.2	45.98	43.98	10.01
4	40	70	0.2	47.11	44.34	43.58	12.05
5	40	80	0.2	45.73	45.68	42.97	11.31
6	40	100	0.2	44.63	45.88	43.95	10.15
7	40	70	0.25	46.89	44.35	44.02	11.59
8	40	80	0.25	45.51	45.7	43.39	10.88
9	40	90	0.25	47.22	43.22	46.36	10.39
10	40	70	0.3	46.52	44.37	44.31	11.29
11	40	80	0.3	45.18	45.74	43.65	10.59
12	40	90	0.3	46.93	43.23	46.64	10.08
13	40	70	0.35	46.35	44.41	44.54	11.01
14	40	80	0.35	44.94	45.77	43.97	10.22

According to the best modes obtained after limiting the possible conditions to optimize daylight to increase the efficiency of daylight in the vernacular house, the best mode according to the percentage of numbers shown in column (DA) and column (100-UDI-2000), is model 1, which is presented in Table 9. According to the case sample of the present study, in this case (DA) has the highest possible limit compared to other models. Indeed, it should be mentioned that the presented model (model 12), in Table 8, shows a higher percentage in terms of the percentage related to the column (100-UDI-2000), but the priority is related to the highest percentage (DA). DA specifies without the need for electric lighting a specific range, and how much it has access to sufficient daylight to perform specific and anticipated activities in that environment, and this issue is preferred in this debate. Also, the percentages related to (DA, 100-UDI, 100-UDI-2000, and UDI-2000) selected for vernacular building 2 (case sample of the current research) are shown in Figure 9 as shown on the plan of the residential house.

Table 9
The best mode determined by Design Explorer to increase daylight efficiency, according to the determined lighting ranges (DA, 100-UDI, 100-UDI-2000, UDI-2000)

Model number	WWR (%)	Building rotation angle (degree)	Shading Depth (m^2)	DA (%)	UDI: (100-UDI) (%)	UDI: (100-UDI-2000) (%)	UDI: (UDI-2000)` (%)
1	40	90	0.15	47.69	43.15	45.75	11.07

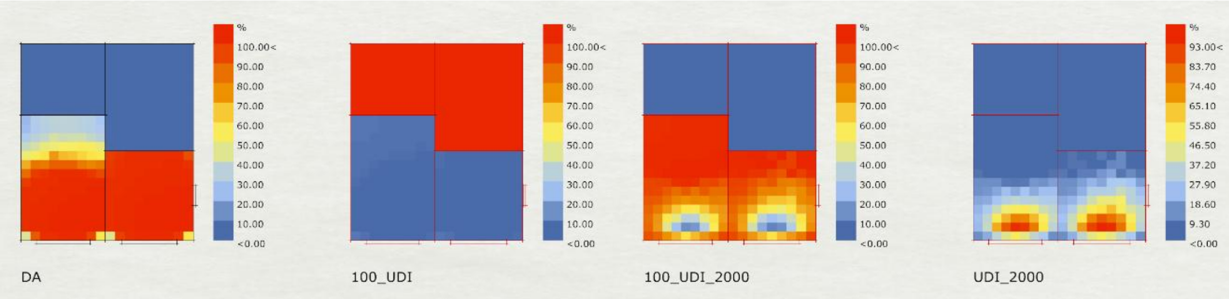

Fig. 9. Percentages related to (DA, 100-UDI, 100-UDI-2000, and UDI-2000) determined for vernacular building 2, through display on the residential house plan

6. Conclusion

This paper has combined the multi-objective optimization approach to increase daylight efficiency in rural residential buildings by using passive systems, because various researches conducted have focused on residential buildings in cities to optimize the efficiency of daylight and to increase the efficiency of energy. Despite the high number of residential houses in the villages, it is possible to create maximum use with little cost compared to active systems with high efficiency by taking advantage of the existing climatic conditions and using passive systems.

In the present study, first, 4 case samples (2 vernacular houses and 2 non-vernacular houses) located in Kang village of Iran were selected. Then, the simulation process of these 4 selected houses was performed using Grass Hopper plugin in Rhino software. Finally, the amount of cooling and heating load , as well as the lighting load of eachhouse, was measured according to the current situation during one year (12 months) using the Ladybug plugin in the Grass Hopper environment. Based on the evaluation consistent with the objectives of the research, one of the vernacular houses was selected (the most optimal house in terms of the total amount of cooling and heating load and lighting load) among the selected samples.

Then, according to the variables determined for the parameters considered in this research (building orientation, Shading depth, and WWR) and after entering the lighting information and converting it to the lighting model in the daylight optimization in the sample under study, the output file with the data. csv format was extracted. Next, after uploading the file in the web Design Explorer environment and by creating restrictions in the determined daylight ranges (DA, 100-UDI, 100-UDI-2000, UDI-2000), we achieve the best possible modes for daylight optimization. Finally, the best possible mode to increase the efficiency of daylight was shown in the case sample selected in Kang village, consisting of 20% WWR, 90-degree rotation angle of the building, shading depth with a depth of 0.35%. These parameters also create 47.69% daylight autonomy (DA), 43.15% useful daylight illuminance (100-UDI), 45.75% useful daylight illuminance (100-UDI-2000), and 11.07% of the useful light illuminance of daylight (UDI-2000). As a result, by achieving the aim of the present study, it can be predicted that this increase in daylight efficiency in the vernacular houses of Kang village can reduce the use of supplementary light in these houses, thus, this issue leads to a reduction in energy consumption. Finally, more optimal conditions can be created for the environment protection.

In addition, it is recommended that in future researches, when evaluating the issue related to the present research, existing sensors related to the topic of lighting should be used and installed in the environment of the study building, so that its information can be used to find more accurate results. Based on the extent of rural residential houses, much more accurate information, in this case, can optimize the impact of increasing the efficiency of daylight and, as a result, reducing energy consumption in Iran. Based on the high costs of purchasing and retaining the sensors of lighting, the present study didn’t use these sensors. To find more accurate results, it is recommended to add other parameters to evaluate the daylight optimization and then by considering the overlap of these parameters' effect on each other, we can evaluate the daylight optimization. It is also suggested that in future researches, the subject of energy evaluation should be done after optimizing the daylight to evaluate its exact impact on the annual energy consumption of a rural residential house.

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