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Evaluation of Optimal Criteria for Designing Solar Greenhouses in Cold Climate Residential Buildings (Case Study: Tabriz, Iran)

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Abstract

Since a major part of energy in cold climates is spent on heating, using alternative methods to heat buildings is of particular importance for buildings. Solar greenhouses are inactive building solutions that absorb solar energy to provide heating in the side spaces. Greenhouse efficiency depends on several factors. The research carried out so far has used these factors in the design of a solar greenhouse to reduce energy consumption, which has finally been compared with the non-applied state of this system. The purpose of this study is to investigate the physical characteristics such as "depth", "protrusion", "roof slope", and "orientation" of solar greenhouses and the influence of each factor in different modes and hours in the cold climate of Tabriz. For this purpose, a simulation has been made using "Energy Plus" software. In the next step, the optimal modes of solar greenhouse design are presented by comparing the different states of each physical factor on the first and the middle day of each month in a 6-hours period. Research results show; increasing the surface while the sun is shining and using more depth when there is no sun will maintain indoor temperature. Also, using two or three-way greenhouses (east and south) increases the efficiency of the greenhouse by 30%. The roof slope has no effect on heating the room adjacent to the greenhouse. Also, the absence of protrusions helps adjust the room temperature relative to the outside environment by up to 20 %. No significant effect on temperature was observed in calculating the ratio of greenhouse area to room area in summer. But in the cold season, a large greenhouse area greatly impacts by up to 15 %.

Keywords:
Solar greenhouse, optimal criteria for design, cold climate, energy consumption, residential buildings.

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INTRODUCTION

In today's world of technology, due to the growing population of the world and the increasing level of welfare of societies, which in many cases leads to an increase in energy consumption, the crisis of supplying energy in a way that is consistent with sustainable development is one of the most important concerns of countries (Hashemi and Heydari, 2012). Iran's per capita energy consumption is more than 5 times that of countries like India and Pakistan and a little less than 2 times. Also, countries like Korea and Japan, whose GDP is several times higher than Iran's, have a per capita consumption of only 16 to 26% more than Iran (Parsa and Sajjady, 2019). Iran's final energy consumption per capita was 13.69, 14.15, 13.96, and 14.22 barrels of crude oil equivalent in 2008, 2009, 2010, and 2011, respectively (Vidadili et al., 2017). In 2009, due to the implementation of the subsidy targeting plan and the sudden increase in the price of energy carriers, the per capita consumption decreased to a small amount. But it has been increasing again since 2010 (Barimani and Kaabi, 2015). Since in developing countries such as Iran, more than 40% of total energy consumption belongs to the construction sector, with the advent of various technologies (IEA, 2020), implementation complexities have increased and decisions on choosing the best strategies and Energy consumption reduction strategies in buildings has become more important (Fathalian and Kargarsharif, 2020).

The average energy consumption in Iranian buildings per square meter is about 310 KW hours per year, which is about 120 KW hours per square meter in a similar situation in European countries. Therefore, energy consumption in Iranian buildings is about 2.5 times that of European countries (Hashemi and Heydari, 2012). Currently, in the building design department, saving energy consumption by paying attention to the placement of spaces in the plan based on matching the pattern of space occupation, choosing the shell suitable for the climate and environmental conditions, dimensions of opening and glass (single pane, double pane, etc.) and finally, appropriate methods are used to replace renewable energies instead of non-renewable energies (Abounoori and Gholizadeh Eratbeni, 2022). In the future, the building design and construction community will be faced with regulations and standards that aim to reduce energy consumption to zero in the building. Thus, in order to meet the new expectations, the need to change the design and use of the building is considered inevitable (Bakhtyari and Fayyaz, 2019). One of these types of energy that can be easily used in buildings is solar energy (Moghaddasi et al., 2016). The use of solar energy in the construction industry creates sustainability that somehow responds to the needs of the current generation without limiting the ability and facilities of future generations to meet their needs (Pourdarbani, 2020).

Achieving this definition is not an easy task and requires the explanation of policies, goals, and strategies through which sustainable designs can be realized in the future (Ghouchani et al., 2021). With 300

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sunny days in more than 2/3 of its area and an average radiation of 4.5-5.5 kilowatt hours per square meter per day and 2800 sunny hours per year, Iran is one of the most important centers of solar energy production in West Asia and in the world (Shahsavari et al., 2018). According to available reports, there are about 700 hours of sunlight in spring, 1050 hours in summer, about 830 hours in autumn, and about 500 hours in winter in Iran (Khorasanizadeh et al., 2014). Therefore, the total energy required by Iran can be provided by using only one percent of the country's area. Since Iran is the second producer and exporter of crude oil and natural gas in the Organization of the Petroleum Exporting Countries (OPEC) (Gorjian et al., 2019), less attention has been paid to renewable energies such as solar energy.

There are several passive and active systems for using solar energy in a building. Each of the solar systems has capabilities and if they are designed and used in spaces and architectural elements, they can reduce the heat load. Obviously, for the optimal use of these systems in architecture, the necessary study must be done to determine the best option (Gilani and Kari, 2011).

Passive solar systems are systems that collect and store solar energy without the use of equipment such as a pump or controller to be used at the right time (Esmaeli and Roshandel, 2020). In this way, the various components of a building simultaneously meet the expectations in the field of architecture, providing stability and safety and optimizing energy consumption in a building. These systems will be among the most efficient systems among other solar systems when energy collection, equipment reduction, and implementation costs are the main design priorities (Hassanien et al., 2016). These systems can be classified into direct receiving, indirect receiving, and separate receiving (Huang et al., 2021).

One type of separate receiving system is the solar greenhouse system. This system receives solar energy directly and absorbs and stores it in walls in order to transfer it to adjacent spaces. This system can be considered an expanded type of thermal wall (Han et al., 2021). Because the glass wall in this system is located at a greater distance than the thermal wall system. Heat transfer from the solar greenhouse to the adjacent space can be done by a common wall, through conduction, or by openings in the common wall, with convective current (Pakari and Ghani, 2019). In fact, the solar greenhouse system is a solar collector that can meet a part of the thermal needs of adjacent spaces and respond to other building functions (Hassanien et al., 2018). The proper functioning of the solar greenhouse depends on the correct design of this space. Optimal solar greenhouse design criteria can eliminate the need for complex thermal calculations by designers.

In this study, the performance of solar greenhouses in a cold climate (Tabriz city in Iran) that requires indoor heating for at least five months of the year has been investigated. In fact, this research is a scientific, analytical, and practical agenda for designing and using solar

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greenhouses specifically in the city of Tabriz and its suburbs. Therefore, this study seeks to answer the following questions:

What are the physical properties that affect the efficiency of a solar greenhouse space? How much does each of these factors affect the efficiency of a solar greenhouse?

RESEARCH BACKGROUND

In the early 1930s, solar homes became popular in the United States. The North American Indians built solar complexes in the 11th and 12th centuries (Huang et al., 2020). The city of "Aluma" is one of those examples, which has three large terraces that extend south of the building from east to west to absorb the maximum heat of the sun in winter. In Iran, the first solar building was constructed in the north of "Science and Technology University" in May 1998 to study and research in the field of energy efficiency, which has reduced the consumption of fossil fuels and environmental pollution (Mohammadpour et al., 2013).

So far, several studies have been conducted in the field of solar greenhouses, some of which are mentioned:

Motard and Fissure (2007) proposed a model for the distribution and reflection of long-wavelength radiation waves inside a connected greenhouse (assuming a uniform air temperature in the greenhouse). They compared the simulation results of their model with the results of measuring a real sample. Using their model, air temperature, greenhouse surface temperature and heat flux to the spaces adjacent to the greenhouse can be obtained. In their research, Oliotti et al. (2008) presented a simple model for evaluating the absorption of solar energy in the greenhouse, using the "Derbelt" simulation program. The most important variables studied included latitude, orientation, geometry, and visual characteristics of opaque and glass surfaces. Using their proposed model, the amount of solar energy absorbed in the greenhouse can be estimated with sufficient accuracy.

Mihalakaku et al. (2000) investigated the effect of factors such as orientation, glass material, greenhouse floor boundary conditions, and underground pipe system on its thermal performance in buildings in four European cities, using the "Transis" simulation program. The results of their research showed that the greenhouse attached to the building significantly increases the indoor temperature in the colder times of the year. But most of the time, it causes the indoor space to overheat during the hot times of the year. But most of the time, it causes the indoor space to overheat during the hot times of the year.

Of course, this phenomenon occurs when the performance of the greenhouse is the same in hot and cold times of the year and no arrangements are made for the release of hot air during the hot times of the year. Mihalakaku (2002) continued the research by examining the effect of three methods of passive cooling, including canopies, underground pipes, and night ventilation. He then offered a way to prevent the greenhouse from overheating in the summer by using the

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"Transis" simulation program. The results of this study showed that using all three methods can improve the thermal behavior of the building connected to the greenhouse. But the most effective way to cool and prevent the building from overheating during the hot times of the year is to combine all three measures. Gilani et al. (2011) concluded that although the greenhouse system reduces radiation to the wall attached to it, acting as a barrier between indoor and outdoor spaces as a result, it causes heat loss in the building reducing the heating load of the building. Fayyaz and Montaser Kouhsari (2013) studied the refrigeration and heat load of a room adjacent to a greenhouse in Tabriz and concluded that in winter the presence of a greenhouse can save up to 30% of heating energy. But This feature is reversed in summer and will cause up to 25% cooling energy loss.

The research studies so far have generally concentrated the form of designing a building utilizing a solar greenhouse in order to reduce energy consumption, which has finally been compared to the unapplied state of the system. In fact, previous studies have been conducted to identify the factors affecting the quality of this system. From the studies conducted in this field, it is possible to extract the factors affecting the executive quality of solar greenhouses. This study, while confirming the accuracy of the effect of these factors, deals with the effectiveness of each factor in different situations and hours. Then, it provides instructions for the optimal design of a solar greenhouse for the city of Tabriz.

RESEARCH METHOD

The aim of the present study is to an applied type, which ultimately leads to the presentation of architectural solutions for reducing the energy consumption of the building. The research method in the present study was a combination of qualitative and quantitative approaches. In different stages of research, descriptive, analytical, simulation, and finally, logical reasoning methods were used. Architectural design is an independent variable and the degree of influence of physical design factors is the dependent variable. This semi-experimental research aims to examine the relationship between independent and dependent variables, to objectively and qualitatively describe the content of concepts, and to collect, classify and analyze the elements and contents. In the first stage, the physical components affecting its thermal performance in the building of qualitative data with an open questionnaire and through interviews and the review of documents and quantitative data used numerically and through the weighting of Delphi questionnaires were prepared.

In this research, 12 professors, experts, and specialists in the field of energy and architecture from the five top universities of Tehran in Iran (Tehran University, Sharif University of Technology, Amir Kabir University of Technology, Tarbiat Modares University and Shahid Beheshti University) Level of activity and field of study and using random sampling, they were selected as the expert team. The validity of the

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questionnaires has been confirmed by expert experts and their reliability through Cronbach's alpha coefficient (0.818).

The first stage includes an open questionnaire, in which the most important effective factors in the optimal design of the greenhouse were provided to the group of experts, and finally, 10 criteria were selected as indicators of the optimal design of the greenhouse. In the second stage, the questionnaire was completed to determine the key factors through weighting in the form of pairwise comparison and systematic analysis (the degree of correlation of variables with numbers between 0-4).

The physical factors selected in this study are: "change in the depth of the greenhouse", "protrusion of the greenhouse from the adjacent space", "slope of the greenhouse", "ratio of room area to the greenhouse", and "orientation of the greenhouse". In the next step, due to the numerical and comparative nature of the research, the simulation method was used with the help of Energy Plus software (version 9.2). Energy Plus Simulation was developed by the US Department of Energy in 2011 and is recognized as one of the most reliable energy modeling software (Amani and Moghadas Mashhad, 2020). The validity of Energy Plus software has been confirmed based on Bestest and ASHRAE 14 standards (Zomorodian and Tahsildoost, 2015). All situations on the first day and half of every month and repeated every 6 hours separately in terms of the amount of solar energy received and daylight have been reviewed and presented in separate charts.

Climatic region studies

The city of Tabriz (latitude: 38.05 / longitude: 46.17 / altitude: 1361 meters) is the capital of East Azerbaijan province. The climate of this region is mostly unstable in spring and the air is in transition and most of the precipitation due to the low-pressure dynamic system of the Mediterranean occurs in the western part of Iran. In winter, the weather is very cold, with a sharp drop in temperature and snowfall, and is hot and dry in summer. Studies show that the city of Tabriz, due to its special geographical location and location in cold climates, has a climatic comfort ratio hour to numerical climatic comfort hours of 17.7%. This means that energy must be consumed to create a climate balance for human physiological conditions (Ghobadian, 2021). The climatic conditions of Tabriz are such that in some months of the year, in order to achieve thermal comfort, in addition to inactive measures, active heating measures are also necessary. National Building Regulations number 19 considers the buildings of Tabriz to be in the group of buildings with high energy consumption and need predominant thermal heating (Rouhizadeh and Farrokhzad, 2020). (Table 1)

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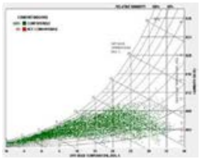
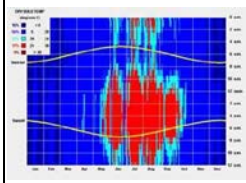
City Name	Latitude	Longitude	Above sea level	Construction group	Range of comfortable conditions of the city	The annual temperature of the city
Tabriz	38.05	46.17	1361	Buildings with high energy consumption and the predominant thermal requirement is heating		

Average monthly air temperature											
December	November	October	September	August	July	June	May	April	Mars	February	January
- 1.2	5.2	16	22.9	28	27.2	22.1	14.8	11.2	0.6	- 0.9	1.4

Assumptions

In the process of entering the initial data required for the simulation, an attempt was made to consider assumptions that are as close as possible to the actual operating conditions in Iran and the city of Tabriz. A room with dimensions of 10 * 10 * 2.8 M3 with a greenhouse of 4 * 4 * 2.8 M3 was considered the basic model. The wall of this room faces the solar greenhouse, which has a window 2 meters wide and 1.5 meters high. The other three walls of this room are adjacent to other buildings. The height of the adjacent buildings is the same as the room. Therefore, they do not create shadows. A number of 5 people were using the room. On weekdays throughout the year, from 4 pm to 8 am the next day, everyone was considered living in the room. But from 8 am to 4 pm, only one person was considered living in the room. On weekends throughout the year, everyone was in the room round-the-clock. It should be noted that the calculation of heat production from individuals, assumes standing and relaxation.

Exterior walls were double-layer clay block walls with 50 mm polystyrene insulation in the middle layer, a 10 mm cement facade in the exterior view, and 15 mm gypsum plaster inside. The inner wall was a clay block lined with plaster. The floor and ceiling were made of reinforced concrete. The room space window facing the solar greenhouse had two layers of 6 mm and 4 mm glass, and a layer of 12 mm air between the two layers.

But the solar greenhouse wall was provided with a layer of 6mm glass. On all days of the year, depending on what time the sun rises and what time it sets, a 250W lamp was used from sunset to midnight, and from midnight to sunrise, no lights were used. Due to the fact that in the day

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only 20% of people are in the room, less ventilation is considered. It is worth mentioning that this reduction of ventilation is both to reduce energy consumption and the effect of receiving solar energy through the greenhouse. At times of the year when the outside air temperature exceeds 25 ° C and the indoor space needs to be cooled, 200m / h of fresh air enters the solar greenhouse from outside, of which 45m / h is used for indoor ventilation and 155m / h is used for solar greenhouse ventilation and the extra heat dissipates. Also, at times of the year when the outside air temperature is less than 21 ° C and the heat of indoor space needs to be raised, 45m / h of fresh air enters the solar greenhouse from outside. This amount of fresh air is used for both solar and indoor space ventilation.

RESULTS

In this section, the physical factors affecting the performance of the solar greenhouse have been simulated in different conditions taking into account the research hypotheses. Each of these situations was simulated on the first and a half day of each month and repeated every 6 hours in Energy Plus software. The results of the study were as follows.

Depth to Facade Ratio (Fixed area)

Situation 1 (more depth): At 6 o'clock in the morning, the presence or absence of a greenhouse does not have much effect on improving the heating conditions. At 12 noon, the temperature of the greenhouse itself is higher than the adjoining room in the cold seasons of the year. Therefore, by installing a ventilation valve, heat can be directed into the environment. At 6 pm and 12 pm, the thermal effect of the greenhouse is felt. (Figure 1)

Situation 2 (equal depth and surface of the facade): At 6 o'clock in the morning, the presence of the greenhouse heats the room more than usual. Since the temperature of the greenhouse is lower than the neighboring room, it turns out that at this time of day (especially in winter), the greenhouse needs insulation. At 12 noon the temperature of the greenhouse is much higher than the adjoining room in the cold seasons of the year. Therefore, by installing a ventilation valve, heat can be directed into the environment. 6 pm and 12 pm are similar to 12 noon. (Figure 2)

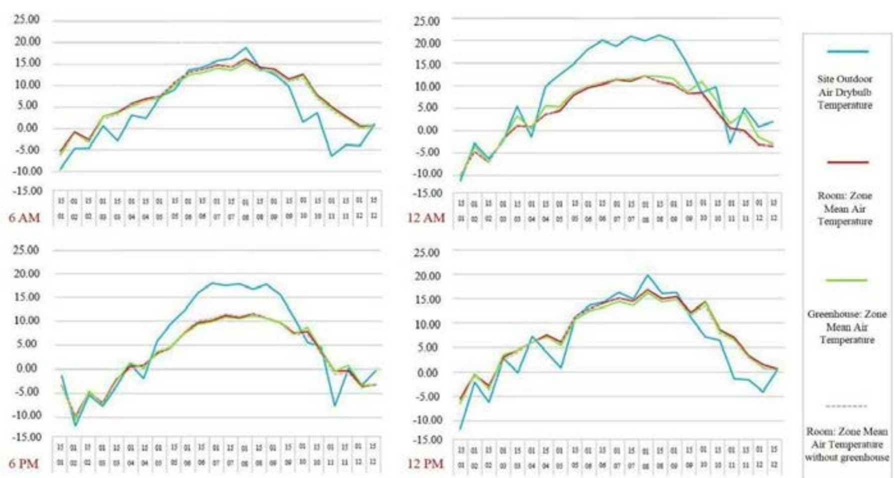

Figure 1. Comparison of temperature at different hours of the situation 1 in depth to facade ratio

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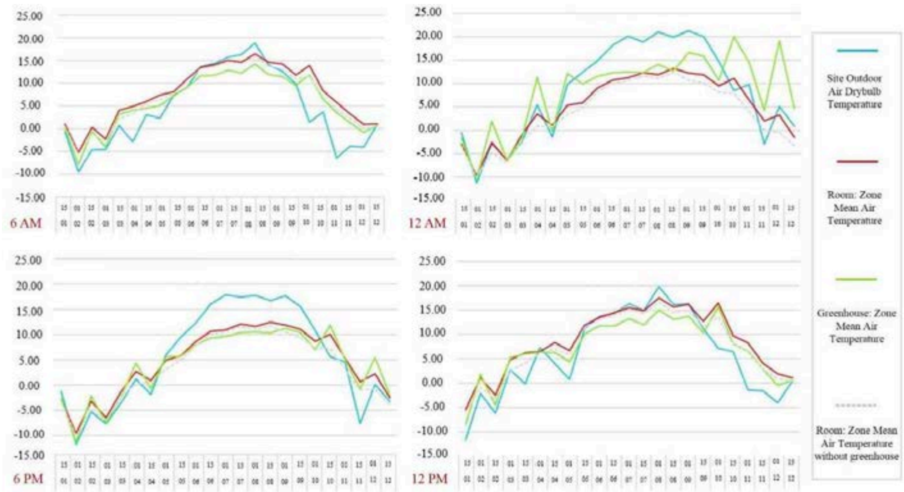

Figure 2. Comparison of temperature at different hours of the situation 2 in depth to facade ratio

Situation 3 (more facade level): At 6 o'clock in the morning, the presence of the greenhouse causes relative heating of the room, more than normal. At 12 noon, the temperature of the greenhouse is much higher than in the adjoining room in the cold seasons of the year. Therefore, by installing a ventilation valve, heat can be directed into the environment. 6 pm and 12 pm In the cold months of the year, the greenhouse and the surrounding area create higher temperatures than usual. Therefore, this mode is recommended. (Figure 3)

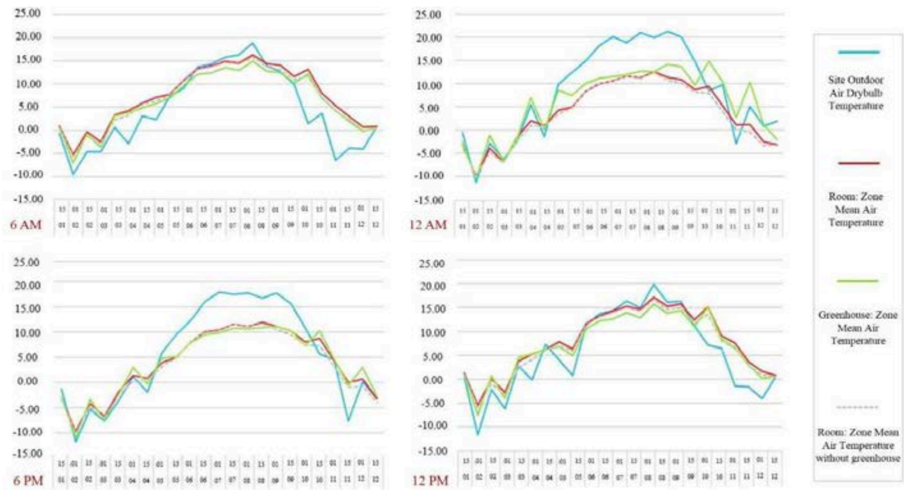

Figure 3. Comparison of temperature at different hours of the situation 3 in depth to facade ratio

Orientation (while maintaining the dimensions and proportions the greenhouse)

West: At 6 o'clock in the morning, the presence of the greenhouse causes relative heating of the adjacent room, more than usual. It does not get too comfortable in the summer, but it is recommended to open the greenhouse windows. At 12 noon, the greenhouse was warmer than other spaces. Similarly, the temperature without the greenhouse was lower than all other conditions, which is a warning for the use of thermal insulation during these hours. The situation was the same at 6 pm and 12 pm. **(Figure 4)**

Southwest: At 6 a.m., the description was the same as before. In addition, in the cold season, thermal comfort was provided to some extent. At 1 o'clock in the afternoon, the greenhouse was warmer than other spaces. Similarly, the temperature without the greenhouse was minimum. The downside here is the cold season. At this time, the room temperature was lower than the greenhouse, which is the same temperature as the environment. At 6 pm and 12 pm at low temperatures, good heating performance was observed in winter. In half of the summer, the greenhouse should be exposed to sunlight and its temperature should be avoided as much as possible. **(Figure 5)**

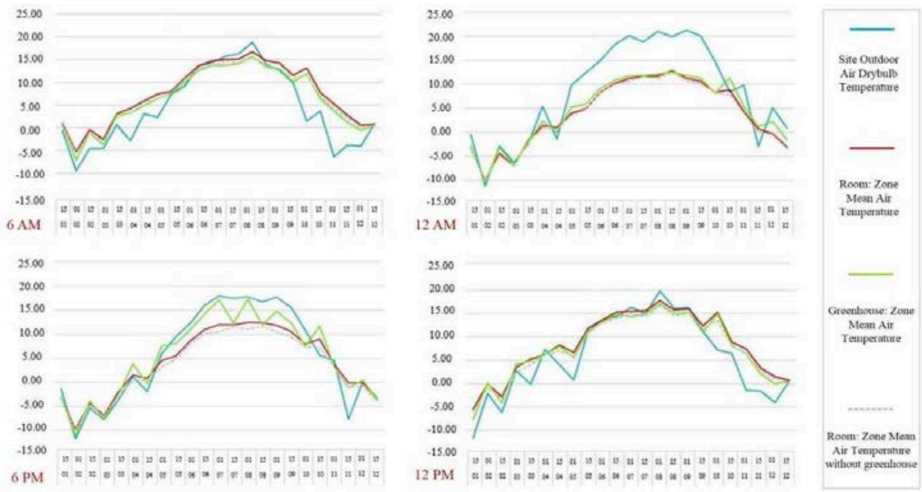

Figure 4. Comparison of temperature at different hours of the West

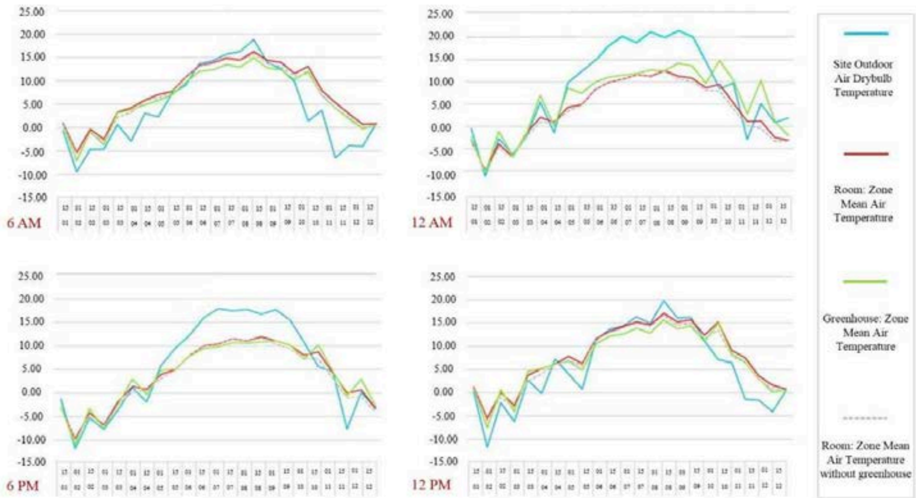

Figure 5. Comparison of temperature at different hours of the Southwest

South: At 6 o'clock in the morning, the presence of the greenhouse causes the relative heating of the room more than usual. Of course, the coolest space is the greenhouse. At 12 noon, the greenhouse temperature was higher than the adjoining room during the cold seasons of the year. Therefore, by installing a ventilation valve, heat can be directed into the environment. At 6 pm and 12 pm in the colder months of the year, the

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greenhouse and the surrounding area had higher temperatures than usual. (Figure 6)

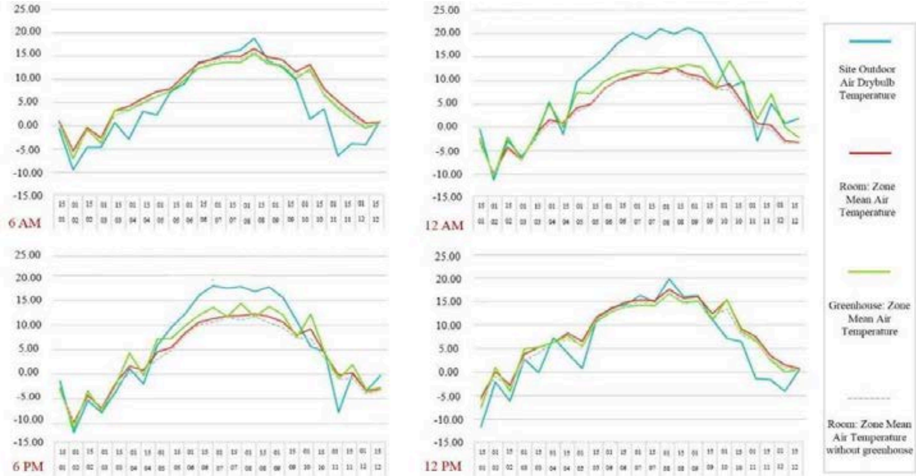

Figure 6. Comparison of temperature at different hours of the South

Southeast: At 7 o'clock in the morning, the presence of a greenhouse in the cold season heats the room. But on summer days, the lack of a greenhouse provides cooler air, which indicates the need for insulation. At 12 noon in the cold season, the greenhouse was warmer than the environment. But the next room is colder than outside. Therefore, an inlet valve is required. In the warm season, due to the low temperature in the state without a greenhouse, it is possible to prevent it from heating by covering the greenhouse. At 6 pm, the greenhouse does not affect heating and cooling. At 12 o'clock at night, the greenhouse is quite effective in the cold seasons. (Figure 7)

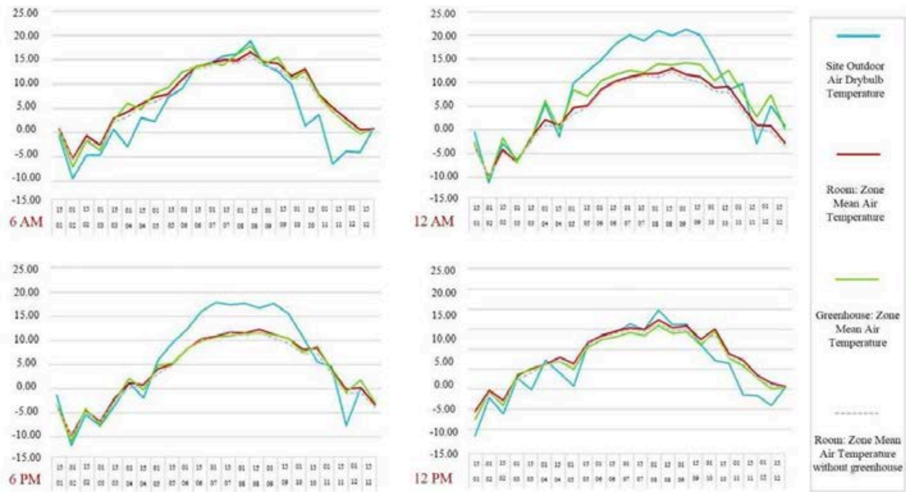

Figure 7. Comparison of temperature at different hours of the Southeast

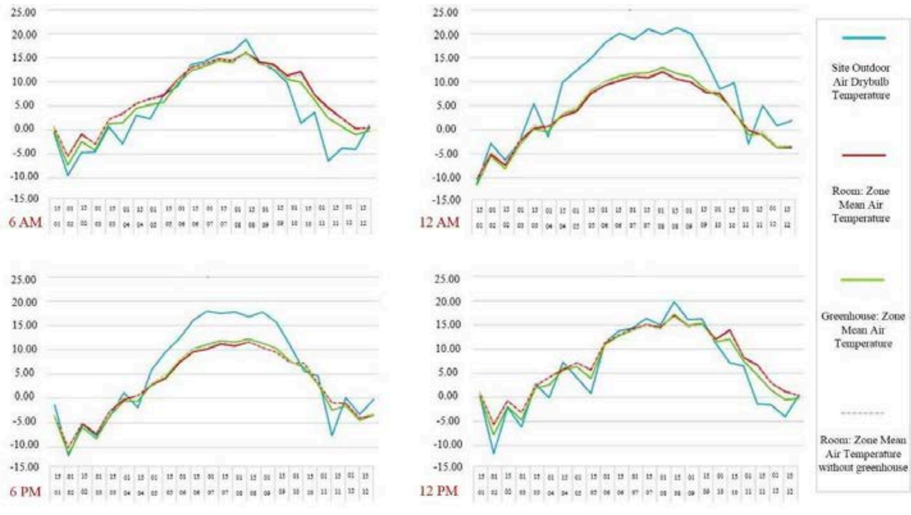

Figure 8. Comparison of temperature at different hours of the East

East: At 6 o'clock in the morning, the presence of a greenhouse in the cold season heats the room. But on summer days, the lack of a greenhouse does not affect the temperature. At 12 noon in the cold season, the greenhouse is warmer than the environment. But the next room is colder than outside. Therefore, an inlet valve is required. In the warm season, due to the low temperature in the state without a greenhouse, it is possible to prevent heating by covering the greenhouse. At 6 pm, the greenhouse has no effect on heating and cooling. At 12 o'clock at night, the greenhouse is quite effective in the cold seasons. **(Figure 8)**

Greenhouse protrusion relative to the room

Situation 1 (fully protruding): The greenhouse temperature in the hot season at 6 am is very cool and can ventilate the interior. At 12 noon, increasing the greenhouse temperature should be prevented by thermal insulation. This increase in temperature at noon is very annoying. At 6 pm in summer, the greenhouse temperature is still higher than room temperature. Therefore, preventing greenhouse ventilation into the space or even blocking radiation to the greenhouse can be effective. At 12 o'clock at night in the cold seasons of the year, the greenhouse is at the same temperature as the environment. Therefore, greenhouse insulation must be provided to minimize heat dissipation. **(Figure 9)**

Situation 2 (3/4 protruding): At 6 o'clock in the morning, the presence of the greenhouse in the cold season heats the room. But on summer days, the lack of a greenhouse provides more cool air. This indicates the need for insulation. At 12 noon in the cold season, the greenhouse is warmer than the environment. But the surrounding space is colder than outside. Therefore, an inlet valve is required. In the warm season, due to the low temperature in the state without a greenhouse, it is possible to prevent it from heating by covering the greenhouse. At 6 pm, the greenhouse has no significant effect on heating and cooling. At 12 o'clock at night, the greenhouse is effective in the cold seasons. **(Figure 10)**

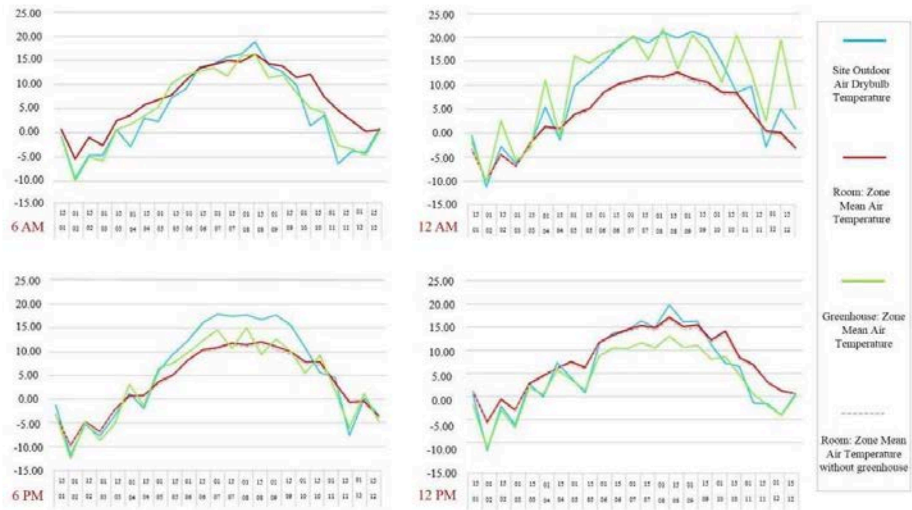

Figure 9. Comparison of temperature at different hours of the situation 1 in greenhouse protrusion

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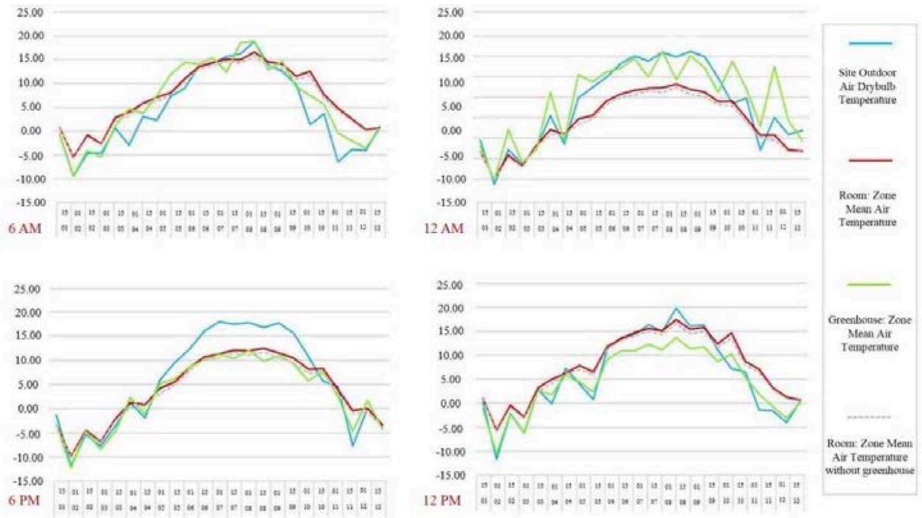

Figure 10. Comparison of temperature at different hours of the situation 2 in greenhouse protrusion

Situation 3 (1/2 protruding): At 6 o'clock in the morning, the presence of a greenhouse in the cold season heats the adjoining room. If the temperature of the greenhouse is higher than the environment, but the room temperature is still in warmer conditions, ventilation between these two spaces is not recommended. At 12 noon in the warm season, the greenhouse was cooler outside and the adjoining room was cooler. Of course, the lowest temperature was provided by the conditions without a greenhouse. In the warm season, the greenhouse temperature rises which emphasizes the need for heat exchange with indoor spaces. At 6 pm and 12 pm in the cold season, the room temperature was warmer. Due to the lack of radiation, greenhouse insulation was required and ventilation exchange with indoor space is not recommended. **(Figure 11)**

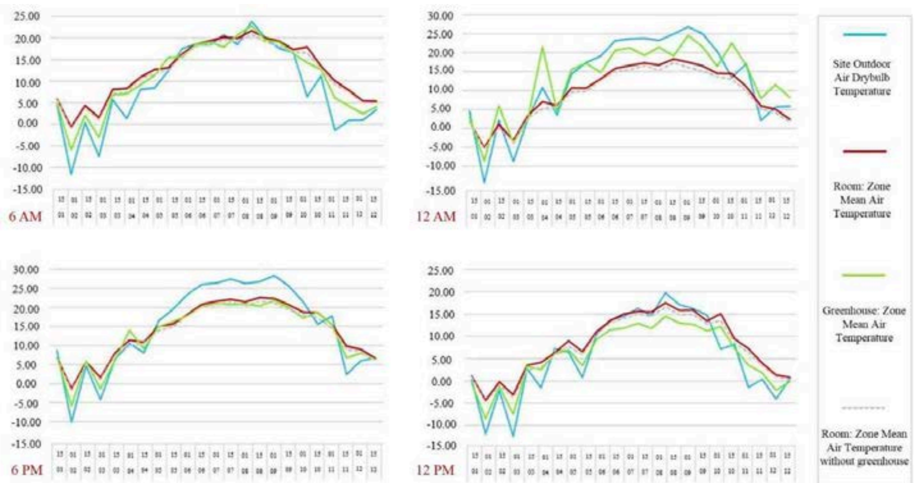

Figure 11. Comparison of temperature at different hours of the situation 3 in greenhouse protrusion

Situation 4 (not protruding): At 6 o'clock in the morning, the presence of a greenhouse in the cold season heats the room. Of course, ventilation in a greenhouse environment is not recommended during this period. It is better to use greenhouse cover insulation during the night. At 12 noon in the cold season, the greenhouse was the hottest part. At this time of summer, the coolest space is the room next to the greenhouse. Of course, the lack of a greenhouse provides a lower temperature. At 6 pm in the cold season, the greenhouse provides considerable heat that can be ventilated. At 12 o'clock in the evening in the cold season, the room next to the greenhouse was warmer and the greenhouse needs to be insulated. Therefore, ventilation between the greenhouse and the room was not recommended. **(Figure 12)**

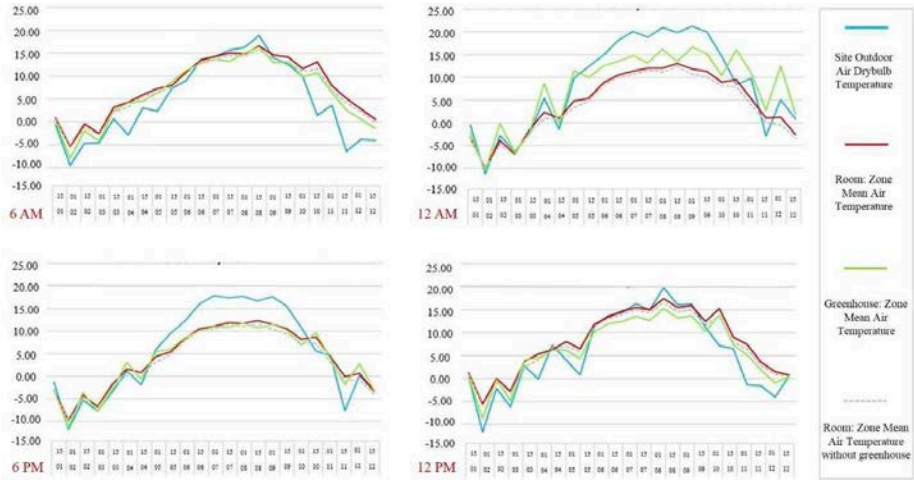

Figure 12. Comparison of temperature at different hours of the situation 4 greenhouse protrusion

Greenhouse roof slope

Situation 1 (15%): At 6 o'clock in the morning, the presence of a greenhouse in the cold season heats the room. Of course, ventilation with a greenhouse is not recommended during this period. It is better to use greenhouse cover insulation during the night. At 12 noon in the cold season, the greenhouse was the warmest space. At 6 pm and 12 pm in the summer, the coolest space was the room next to the greenhouse. Of course, the lack of a greenhouse provides a lower temperature. **(Figure 13)**

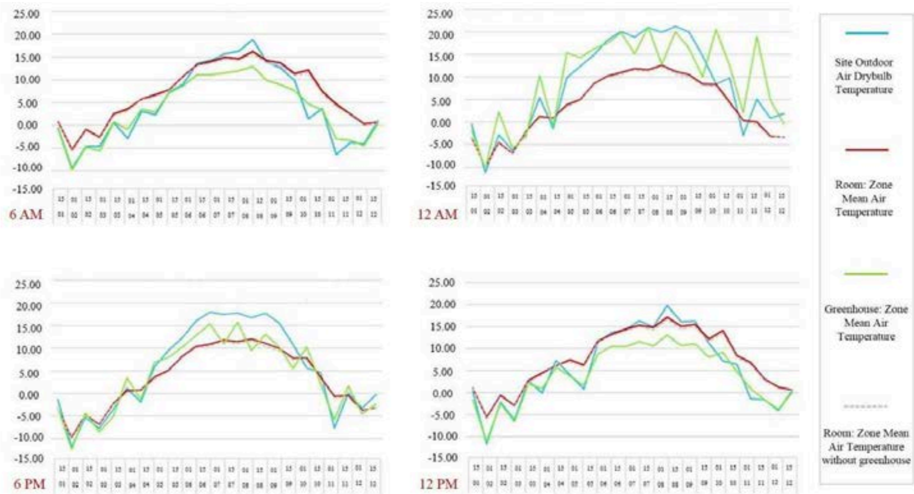

Figure 13. Comparison of temperature at different hours of the situation 1 in greenhouse roof slope

Situation 2 (30%): In this item, all modes are similar. At 6 pm, the greenhouse provides considerable heat in the cold season, which can be ventilated into the room. On 12 nights in the cold season, the room next to the greenhouse was warmer and the greenhouse must be insulated from the environment. Ventilation between the greenhouse and the room

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is not recommended, because the greenhouse is almost the same temperature as the outside environment. **(Figure 14)**

Situation 3 (45%): All situations are the same in this item. **(Figure 15)**

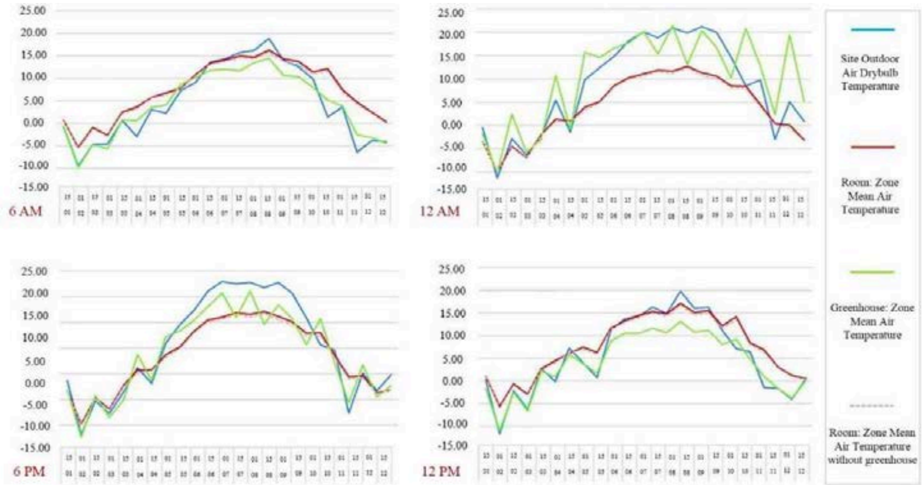

Figure 14. Comparison of temperature at different hours of the situation 2 in greenhouse roof slope

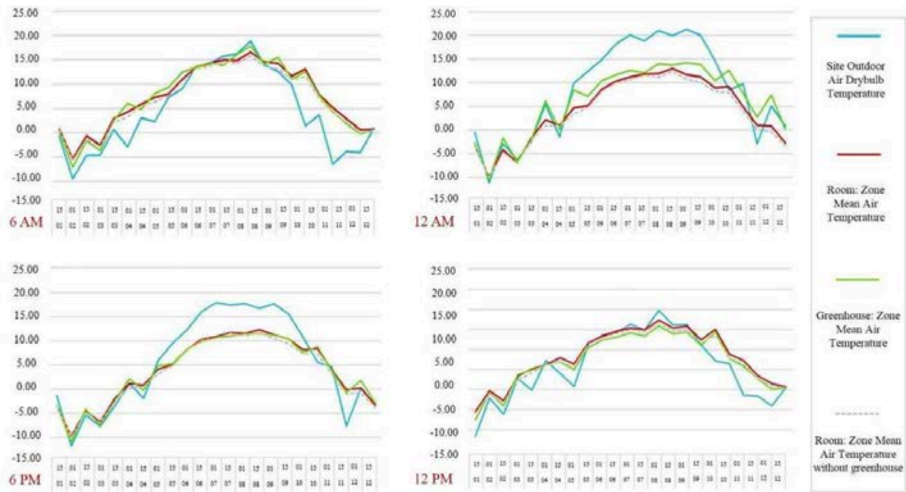

Figure 15. Comparison of temperature at different hours of the situation 3 in greenhouse roof slope

It is important to note that the results are based on Energy Plus software modeling. Although the output of this software has a relative error, it has a lower error rate than other energy analysis software. On the other hand, in the analysis of this research, a comparative study of different states of each feature with the sample case was considered and the amount of energy was compared to the basic model. As a result, the possible errors are equal in all cases and do not have a major effect on the energy consumption of the building in different cases.

DISCUSSION

By examining different conditions of depth-to-facade ratios, it can be concluded that at 6 o'clock in the morning in all seasons, the higher the ratio of façade-to-depth, the higher the temperature of the room adjacent to the greenhouse. However, in the cold season, which is more important in this study, this difference is not significant at this time. At 12 noon, this happens completely differently, and the deeper it is, the more it raises the temperature of the adjacent room. Therefore, this mode will be widely used in the cold season. At 6 pm, similar to 12 pm, depth still affects heating. But unlike 12 noon, there is no significant change in the summer season. At 12 o'clock at night and in the cold months of the year, the first mode with more depth provides more temperature. But in the summer, there is no significant change between different situations. Finally, it can be concluded that the higher the depth of the greenhouse, the warmer the space adjacent to the greenhouse during the hours when the sun is in the sky. But during the hours when the sun is not in the sky, the heat is usually provided by increasing the level of the greenhouse. Therefore, an average is recommended throughout the year. The results of the research of Abdolkhaleghi et al. (2021) also show that the maximum length, i.e. 5 meters, has the highest amount of energy intake due to the increase of the south-facing front. But the desired depth is equal to 1 meter, and with its decrease or increase, the absorbed solar energy decreases.

Comparing the temperature of the room adjacent to the greenhouse in different directions of the sun, it can be concluded that at 6 am in the cold season, the directions of west, south, and southeast provide the highest temperature. But in the warm seasons of the year to the east, the conditions are more favorable. Of course, since there is no significant difference compared to the situation without a greenhouse, it is possible to integrate the greenhouse with the interior space during this period. At 12 noon on all days of the year, the coldest temperature is measured in the east. In the cold seasons of the year, more heat is provided towards the south and southeast. At 6 pm in the warm seasons of the year, the lowest temperature can be observed in the east. This temperature is lower than the absence of a greenhouse. At this hour and this season, the warmest temperature is created in the western direction. But in the cold season, they still work better in the south and southeast and have higher temperatures.

At 12 o'clock at night, the coolest temperature is in the east in all seasons. Therefore, due to the lower temperature without greenhouses in summer, the lack of greenhouses in this season is preferable. In the cold season, as in the previous hours, they have better performance for the south, southeast, and west. The results of the research of Mobtaker et al. (2019) also show that the single-span greenhouse in the east-west extension and the south front has received about 8% more solar radiation in all months of the year compared to other forms.

In terms of protrusion and its effect on greenhouse temperature, it can be said that the more protrusion, the less impact in winter. At all hours in all seasons, the absence of protrusions helps to moderate the room temperature more than the outside environment. Of course, in summer, the absence of a greenhouse in all cases provides a cooler temperature, which can be used by measures to remove the greenhouse or combine the greenhouse with other indoor spaces. The temperature difference between the states during the hours with radiation is less than when there is no radiation. It is beneficial to use thermal insulation during these

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hours to maintain the internal temperature. The results of Bakhtyari and Fayaz's research (2020) show that increasing the length of the greenhouse protrusion leads to an increase in receiving solar energy. This difference is because Bakhtiari and Fayaz's research was conducted in a hot and dry climate. While the present study was investigated in a cold climate.

According to the diagrams at different time intervals, it can be concluded that the slope of the roof has no effect on the room heating adjacent to the greenhouse. Of course, this result is contrary to the prediction. Because it was predicted that based on the change of slope, the angle of radiation would change and affect the temperature of the room. This issue is due to the angle of radiation in the city of Tabriz. Because the weather is cloudy and cold on most days. The results of the research of Moghaddasi et al. (2022) based on the simulated model of the solar greenhouse in the Kermanshah region (cold climate) show that the angle of the roof slope is 50 degrees. This difference is due to the radiation angle in Tabriz city. Because on most days of the year, the weather in this city is cloudy and cold.

In the investigation of the ratio of the effect of the area of the greenhouse to the area of the room in the hot season, there is no significant effect on the temperature. But in the cold season, the larger the area of the greenhouse, the greater the effect. This trend can be seen at all hours of the day and night. Areas higher than 20% can be included. The research results of Çakır & Şahin (2015) also show that rectangular and pyramidal greenhouses, which have a larger area than cylindrical and oval greenhouses, increase productivity in cold regions.

According to the analysis, the following can be used as a guide for the optimal design of the greenhouse in the climate of Tabriz and Sardsir climate in general:

- During the period of the presence of the sun during the day due to the radiation, the wide surface on the facade provides more heat, and when there is no radiation, the greater depth helps to maintain the internal temperature. In fact, the surface causes thermal energy loss. As a result of this observation, reducing and increasing the depth of the greenhouse in different seasons can be helpful.

- The south, southeast, and southwest directions have provided the most heat in the summer season, which was predictable. But the east direction in summer moderates the heat. Using 2- or 3-way greenhouses helps to improve the efficiency of the greenhouse in different seasons.

- The larger the surface of the greenhouse, the higher the amount of heating produced. This process is characterized by a linear rise, but the slope of this rise is different at different times. Choosing the size of the greenhouse, depending on the area of the interior, can be chosen under the influence of other factors.

- Protrusion of the greenhouse means increasing the contact surface with the environment and reducing the contact surface of the greenhouse with the internal environment. As much as the increase in surface area increases the temperature of the greenhouse, the temperature of the room adjacent to it has not increased significantly, which is obvious if ventilation is installed between these two spaces.

CONCLUSION

The results of this study show that in the climatic conditions of Tabriz, comfort conditions are limited without any measures. Also, in the cold seasons of the year, solutions for using internal heat receiving and direct passive solar receiving are suggested. So, in half of a year, the use of solar greenhouse heating in that climate is justified. Based on the literature review as well as analysis of residential buildings in Tabriz, in response to the first research question (What are the physical characteristics affecting the efficiency of a solar greenhouse space?), Five criteria were selected for evaluation. These criteria are: "change in depth of the greenhouse", "protrusion of the greenhouse from its adjacent space", "slope of greenhouse", "ratio of room area to greenhouse area", and "orientation of greenhouse".

The results of the analysis of each of these criteria in response to the second research question (What is the impact of each of these factors on the efficiency of the solar greenhouse?) show a large area in the presence of the sun during the day due to radiation. It provides more heat on the facade and helps maintain the internal temperature in absence of deeper radiation.

It provides more heat on the facade and helps maintain the internal temperature in absence of deeper radiation. In fact, the surface wastes heat energy. As a result of this observation, reducing and increasing the depth of the greenhouse in different seasons can be helpful. The south and southeast directions provide maximum heat in summer. But eastward in summer is a moderator of heat. The use of two- or three-way greenhouses helps improve the efficiency of the greenhouse in different seasons.

The higher the area of the greenhouse, the more heat is produced. This process follows a linear ascent. But the slope of this ascent varies at different times. The greenhouse area can be calculated depending on many factors mostly depending on the interior area. Greenhouse protrusion means increasing the level of contact with the environment and reducing the level of contact of the greenhouse with the indoor environment. Increasing the area will raise the greenhouse temperature, but the temperature of the adjacent room has not increased significantly. If ventilation is installed between these two spaces, the temperature difference will be determined. The slope of the greenhouse roof in this climate has been studied in different situations and according to the software outputs, it has no effect on the rate of receipt. In addition to the presence of a greenhouse to heat the building, how to use it, including the use of cover insulation and ventilation restrictions to improve the efficiency of the greenhouse, is mandatory. This is where the user's role in inactive systems comes into play.

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To design a greenhouse that can meet expectations accurately, these five criteria must be considered along with other factors such as "type of translucent glass", "heat transfer method", "insulation", etc., which could be studied in future research studies. Although these characteristics have been analyzed and evaluated for the climate of Tabriz, the results may be different for other cities. By comparing these features in different climates, a better greenhouse design can be created.

REFERENCES

Abdolkhaleghi, P., Sabernejad, Z., Fayaz, R., (2021), Optimal framework of sunspace based on energy performance in residential buildings in cold climate of Iran (Case study: Sanandaj City). Haft Hesar J Environ Stud, 10 (36), 5-18. http://hafthesar.iauh.ac.ir/article-1-1382-en.html

Abounoori, E., Gholizadeh Eratbeni, M., (2022). Economic Evaluation of Solar Electricity (Photovoltaic) Based on the Space Available in the Building in Different Climates of Iran. Journal of Renewable and New Energy, 9(2), 150-157.
https://www.jrenew.ir/article_152217.html?lang=en

Amani, N., Moghadas Mashhad, M., (2020). The Feasibility of Construction of Zero-Energy Building in the Cold and Semi-Arid

Climate (Case Study: Mashhad). Journal of Environmental Science and Technology, 22(5), 57-71.
https://doi.org/10.22034/jest.2020.36362.4297

Bakhtyari, V., Fayaz, R., (2020). Optimization of semi-open spaces of apartment houses to become a sunspace using simulated annealing algorithm. Journal of Architecture in Hot and Dry Climates, 8(11), 183-209. https://doi.org/10.29252/ahdc.2020.1986

Bakhtyari, V., Fayyaz, R., (2019). Capabilities and Limitations of Energy Optimization Tools in Architectural Design Phase. Iranian Journal of Energy. 22, 127-150. http://necjournals.ir/article-1-1449-fa.html

Barimani, M., Kaabi, D., (2015). Renewable Energy Developing in Iran (Investigating Objections and Presenting Approaches). Journal of Renewable and New Energy, 2(1), 28-34.
https://www.jrenew.ir/article_49125.html?lang=en

Çakır, U., Şahin, E., (2015). Using solar greenhouses in cold climates and evaluating optimum type according to sizing, position and location: A case study. Computers and Electronics in Agriculture, 117, 245-257. https://doi.org/10.1016/j.compag.2015.08.005

Esmaeli, H., Roshandel, R., (2020). Optimal design for solar greenhouses based on climate conditions. Renewable Energy. 145, 1255-1265. https://doi.org/10.1016/j.renene.2019.06.090

Fathalian, A., Kargarsharif, H., (2020). Investigating the Effect of Different Energy Saving Strategies on Energy Rating of Building by Design Builder Software (Case Study: Office Building). Journal of Environmental Science and Technology. 22, 199-214. doi: 10.22034/jest.2019.42973.4590

Fayyaz, R., Montaser Kouhsari, A., (2013). Analysis of Greenhouse Application to Save Energy Consumption in Residential Buildings, Third International Conference on New Approaches to Energy Conservation, Tehran.

Ghobadian, V., (2021). Climatic study of traditional Iranian buildings. Tenth ed., University of Tehran Press, Tehran

ICONARP – Volume 11, Issue 1 / Published: 27.06.2023

Ghouchani, M., Taji, M., Cheheltani, A.S., Chehr, M.S., (2021). Developing a perspective on the use of renewable energy in Iran. Technological Forecasting and Social Change, 172, 121049. https://doi.org/10.1016/j.techfore.2021.121049

Gilani, S., Kari, M.B., (2011). Investigation of Greenhouse's Thermal Performance in Residential Buildings of Cold Climate Case Study: City of Ardebil. Modares Mechanical Engineering. 11, 147-157. http://mme.modares.ac.ir/article-15-1022-fa.html

Gorjian, SH., NematZadeh, B., Eltrop, L., Shamshiri, R.R., Amanlou, Y., (2019). Solar photovoltaic power generation in Iran: Development, policies, and barriers. Renewable and Sustainable Energy Reviews, 106, 110-123. https://doi.org/ 10.1016/j.rser.2019.02.025

Han, F., Chen, Ch., Hu, Q., He, Y., Wei, Sh., Li, C., (2021). Modeling method of an active–passive ventilation wall with latent heat storage for evaluating its thermal properties in the solar greenhouse. Energy and Buildings. 238, 110840. https://doi.org/10.1016/j.enbuild.2021.110840

Hashemi, F., Heydari, S., (2012). Optimizing Energy Consumption in Residential Buildings in Cold Climates. Soffeh. 22, 75-86. https://soffeh.sbu.ac.ir/article_100137.html

Hassanien, R., Hassanien, E., Li, M., Lin, W.D., (2016). Advanced applications of solar energy in agricultural greenhouses. Renewable and Sustainable Energy Reviews. 54, 989-1001. https://doi.org/10.1016/j.rser.2015.10.095

Hassanien, R., Hassanien, E., Li, M., Tang, Y., (2018). The evacuated tube solar collector assisted heat pump for heating greenhouses. Energy and Buildings. 169, 305-318. https://doi.org/10.1016/j.enbuild.2018.03.072

Huang, L. Deng, L., Li, A., Gao, R., Zhang, L., Lei, W., (2020). Analytical model for solar radiation transmitting the curved transparent surface of solar greenhouse. Journal of Building Engineering, 32, 101785. https://doi.org/10.1016/j.jobe.2020.101785

Huang, L., Deng, L., Li, A., Gao, R., Zhang, L., Lei, W., (2021), A novel approach for solar greenhouse air temperature and heating load prediction based on Laplace transform. Journal of Building Engineering. 44, 102682. https://doi.org/10.1016/j.jobe.2021.102682

International Energy Agency (IEA), (2020). World energy outlook. Paris: OECD.

Khorasanizadeh, H., Mohammadi, K., Mostafaeipour, A., (2014). Establishing a diffuse solar radiation model for determining the optimum tilt angle of solar surfaces in Tabas, Iran. Energy Convers Manage, 78, 805–14. https://doi.org/ 10.1016/j.enconman.2013.11.048

Mihalakakou, G., (2002). On the Use of Sunspace for Space Heating/Cooling in Europe. Renewable Energy. 26, 415-429. https://doi.org/10.1016/S0960-1481(01)00138-0

Mihalakakou, G., Ferrante, A., (2000). Energy Conservation and Potential of a Sunspace: Sensitivity Analysis. Energy Conversion & Management. 41, 1247-1264. https://isiarticles.com/bundles/Article/pre/pdf/25533.pdf

Mobtaker, H.G., Ajabshirchi, Y., Ranjbar, S.F., Matloobi, M., (2019). Simulation of thermal performance of solar greenhouse in north-west of Iran: An experimental validation. Renewable Energy, 135, 88-97. https://doi.org/10.1016/j.renene.2018.10.003

DOI: 10.15320/ICONARP.2023.241

Moghaddasi, M., Hiedari, S., Shahcheraghi, A., (2022), Analysis and Comparison The Thermal Performance of Solar Greenhouse (Simulated Model and Portotypic Model) in The Cold and Mountainous Climate of The Country (Case Study: Iran, Solar Greenhouse in Kermanshah City). Honar-Ha-Ye-Ziba: Memary Va Shahrsazi, 27(1), 5-18. https://doi.org/10.22059/jfaup.2022.250112.671934

Moghaddasi, M.M., Heidari, Sh., Shahcheraghi, A., Daneshjoo, Kh. (2016). Evaluation of the optimal model of solar greenhouse in residential buildings of temperate and mountainous climate of the country (Case study: Kermanshah). Journal of Urban and Rural Management. 15, 489-504. http://ijurm.imo.org.ir/browse.php?a_id=1442&slc_lang=fa&sid=1&ftxt=1

Mohammadpour, A., Motie, R., Rezamanesh, M., (2013). Investigating the heating effect of skylights, patios and greenhouse systems in Urmia. Third International Conference on New Approaches to Energy Conservation, Tehran.

Mottard, J.M., Fissore, A., (2007). Thermal Simulation of an Attached Sunspace and its Experimental Validation. Solar Energy. 81, 305-315. https://doi.org/10.1016/j.solener.2006.07.005

Oliveti, G., De Simone, M., Ruffolo, S., (2008). Evaluation of the Absorption Coefficient forSolar Radiation in Sunspaces and Windowed Rooms. Solar Energy. 82, 212-219.
https://doi.org/10.1016/j.solener.2007.07.009

Pakari, A., Ghani, S., (2019). Airflow assessment in a naturally ventilated greenhouse equipped with wind towers: numerical simulation and wind tunnel experiments. Energy and Buildings. 199, 1-11. https://doi.org/10.1016/j.enbuild.2019.06.033

Parsa, H., Sajjady S.Z., (2019). Studying the Trend of Sustainability Indices of Energy in the First Half of Iran's 20-Year Vision. Quarterly Journal of the Macro and Strategic Policies, 6(4), 546-567.
http://dx.doi.org/10.32598/JMSP.6.4.546

Pourdarbani, R., (2020). Review of Current Status and Future Demand for Renewable Energy in Iran and its Marketing. Journal of Renewable and New Energy, 7(1), 118-124.
https://www.jrenew.ir/article_93859.html?lang=en

Rouhizadeh, A.R., Farrokhzad, M., (2020). Regulation of environmental conditions, Seventh ed., Asr Kankash Publications, Tehran.

Shahsavari, A., Yousefi, H., Shahveran, E., (2018). The share of solar energy from the world energy basket in 2030. Journal of Renewable and New Energy, 5(2), 116-121.
https://www.jrenew.ir/article_79886.html?lang=en

Vidadili, N., Suleymanov, E., Bulut, C., Mahmudlu, C., (2017). Transition to renewable energy and sustainable energy development in Azerbaijan. Renewable and Sustainable Energy Reviews, 80, 1153-1161. https://doi.org/10.1016/j.rser.2017.05.168

Zomorodian, Z., Tahsildoost, M., (2015). Validation of energy simulation software in building with experimental and comparative approach. Iranian Journal of Energy, 18(4), 115- 132.
http://necjournals.ir/article-1-803-en.html

Resume

Arian Babaei is an architect who graduated in Architectural Engineering from University of Guilan in 2019 with his research-based thesis project focusing on bio architecture methods. Since then, he has started to keep his concentration on his favorite field, and he has been researching in energy efficient design and ecological retrofitting of existing buildings. Now, He has several international work experiences in this area which makes him an expert in sustainable design.

Dr. Pari Alavi is an expert of architecture and Official member of the road and urban department. She has obtained her Ph.D. with an average of 19/43 in 2022 from the Islamic Azad Zanjan University. Her major research interests are in architecture and urban regeneration. She has cooperated as a reviewer for several scientific journals such as IJEE, IJBP, FoAR .... She has presented more than 60 articles on related subjects at national and international conferences and published more than 10 papers in several journals.

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