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Energy performance sensitivity analysis on building's passive technologies effective parameters, in an NZEB EnergyPlus-simulated villa in Tehran's weather conditions with OFAT methods

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ABSTRACT

As it is clear, today's important subject is energy and ways to decrease its consumption. This subject gets more critical in countries with difficulty providing energy for their building consumption, which is responsible for about 30% of annual energy consumption in the whole country. Iran, because of its geographical location, confronts these problems. Passive technologies are essential in near-zero-energy buildings to reduce annual energy consumption. This research aims to determine which passive techniques have the most impact on the annual energy consumption of buildings in Tehran's climate, as well as to identify the most critical parameters of these techniques. The literature review revealed a gap in research, as current studies focus on simulating these techniques separately in unique Tehran-based geometries. The present study seeks to address this gap by analyzing the real-world and practical application of passive techniques in Tehran's weather conditions. In this research effects of using three significant passive technologies: roof vegetation, smart blinders, and thermochromic windows are studied separately in EnergyPlus software. The result of this research is that using smart blinders and Thermochromic windows at their optimum condition can reduce the annual energy consumption of a building in the climatic circumstances of Tehran by about 56.51% and 37.94%, respectively.

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1. Introduction

The present era is marked by a pressing need to meet human energy requirements due to the surging trend of population growth, urbanization, and improved living standards. The building sector accounts for a significant portion of energy consumption, approximately 30% on average [1]. As a result, researchers have focused on reducing energy consumption in buildings through the implementation of green building or zero-energy building concepts, which involve the use of both active technologies like photovoltaics and passive technologies such as smart glazing.

The roof of a building is often exposed to direct sunlight and heat exchange with the exterior, leading to unwanted heat transfer. On the other hand, windows allow light to enter a building but can also contribute to unwanted

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heat gain. To mitigate this, several studies have investigated the use of thermochromic glasses and smart blinds to control heat transfer from windows and green roofs, reducing roof heat transmission. Passive technologies can significantly reduce energy consumption, while the impact of active technologies, such as photovoltaics, can vary. Recent studies have shown that active technologies can cover a building's annual energy consumption.

Feng et al. investigated the energy-saving potential of green vegetation in a highly occupied LEED Gold-certified building in Canada. They utilized DesignBuilder software for energy modeling and EnergyPlus software for detailed energy simulations. The study simulated three scenarios of green vegetation and found that it significantly reduces negative heat transfer through the building facade during both summer and winter months[2]. Ouldboukhitine et al. conducted an experiment using a 1:10 scale urban canyon with a 4 cm concrete wall thickness and a full-scale green roof to investigate the impact of green roofs on building performance. Their findings showed that, during the summer, the green roof resulted in a 20 °C reduction in maximum roof surface temperature. Additionally, the study revealed that green roofs protect the roof membrane from high-temperature fluctuations, which can increase the roof's longevity and delay the timing of peak membrane surface temperature by several hours[3].

Vera et al. conducted a detailed analysis and comparison of two heat and mass transfer models for vegetative roofs developed by Sailor (2008) and Tabares-Velasco and Srebric (2012). By comparing the main equations governing heat transfer through a vegetative roof, they highlighted similarities and differences between the two models. Both models were programmed in MATLAB, and the thermal capacitance of the substrate was implemented using the finite difference method. Their results showed that both models provide similar predictions of substrate temperatures. However, the study revealed significant differences in the way they evaluate latent (evaporation) and sensible (convective) heat fluxes, suggesting that at least one of them may be miscalculating these heat fluxes[4]. Mungur et al. investigated the impact of green roofs on a building's performance in a hot and humid climate, specifically in Mauritius in the Indian Ocean. The study found that the presence of green roofs in this climate led to a steady heat flow through the roof during the summer and lowered the building's maximum indoor temperature[5]. In the realm of green roofs, numerous studies have explored various factors that influence energy consumption reduction. One such study, conducted by Khabaz et al, analyzed the impact of different green roof types in various climatic regions of Saudi Arabia. The study compared the effect of green roofs with an air insulation layer to that of a typical roof and found that energy consumption was reduced by approximately 87%. The results indicated that the use of short shrubs was more effective than grass in reducing energy consumption[6]. In another study, Piero Bevilacqua et al. used the TRNSYS software to investigate the impact of green roofs on energy consumption. The results showed that green roofs without insulation performed best in terms of annual energy consumption, both in summer and winter [7]. Stefano Cascone et al. conducted a study to address the issue of the weight of green roofs affecting the stability of the building. The study aimed to find new methods to reduce the weight of green roofs. The results showed that these methods reduced the cooling load by 31% to 35% and the heating load by 2% to 10% in the Mediterranean climate of Catania [8]. In a study by Hernandez et al., conventional and green roofs were compared in eight cities in Mexico. EnergyPlus software and experimental data were used in the comparison. The results showed that in hot regions, the indoor temperature of a building with a green roof dropped by 3 to 4.7 degrees Celsius. In temperate areas, the cooling load was reduced by up to 99% and the heating load increased by up to 25% with the use of green roofs. The study also found that the use of green roofs reduced carbon dioxide production by 45.7% and the economic recovery period for green roofs from savings was 8.8 years [9]. Algarni et al. aimed to optimize energy consumption in office buildings by investigating the potential of green roofs with minimal impact on the roof structure. They used a descriptive-analytical research approach and found that green roofs with shallow-rooted grass vegetation have the least impact on the roof structure and can optimize the energy consumption of cooling and heating systems[10].

In their study, Al Touma et al. used external shaders at a constant angle to examine their effect on energy consumption in a building, considering their geographical location. The building was modeled using the EnergyPlus software and the results were validated with experimental data. The results showed that using an external shader at a 90-degree angle in the southern direction of the building reduced energy consumption by 18.6% to 20.6%, while using these shaders in the northern direction of the building reduced energy consumption by 7.7% to 9.1%. The maximum difference between the modeling results and experimental data was between 13.5% and 11.8%[11]. In another study, Dongsu Kim et al. simulated a building using EnergyPlus software and various passive technologies, including double-glazed windows and exterior and interior shading. They found that using these technologies resulted in energy savings of 40% for heating, 2% for cooling, and 5% for total energy load compared to the primary conditions. They concluded that the use of double-glazed windows and exterior and interior shading could reduce the overall heat load and building lighting load by 27% and 52%, respectively[12]. Naderi et al. simulated and optimized smart blinders using EnergyPlus and jEPlus software. Results suggest that the optimization method could reduce a building's total annual energy consumption by 2.8% to 47.8% compared to a basic design. The results highlight the impact of the appropriate selection of shading specifications and control strategy parameters on preventing energy loss and enhancing thermal and lighting comfort for building occupants[13].

Lu et al. conducted a simulation study on an office building to compare the effectiveness of various shading and glazing options, including conventional static glazing, exterior static and kinetic shades, dynamic glazing, and dynamic glazing combined with static or kinetic shades. They proposed a decision-making method for designers to select the most appropriate shading and glazing options based on their evaluation criteria. The authors also developed a scoring system to assess the overall performance of each option[14].

In this study, Ryu et al. aimed to quantify the impact of blinds on heat transfer and thermal decay, and their subsequent effects on diffuser discharge temperatures, temperature profiles, supply airflow rate, and energy consumption in UFAD systems. They compared experimental data with simulation results to analyze thermal decay and cooling energy consumption according to the angle of the blinds. Their study revealed that better temperature stratifications increased the return temperature due to the plume phenomenon, despite the reduction in indoor cooling load by the blinds' shading effect. This resulted in an increased cooling coil load and heat storage in the concrete slab. The authors suggested that their findings provide insight into the relationship between blind angle, thermal stratification, and cooling energy usage in UFAD systems[15].

Kokogiannakis et al. studied the potential energy requirements for heating and cooling a highly glazed tall office building using a thermochromic glazing system, compared to two heat mirror units and a clear triple-glazed window. They used the ESP-r simulation program to account for the dynamic optical properties of thermochromic glass. Their results showed that thermochromic glass may not be effective in cold climates, where heat mirror glazing systems could offer higher energy savings, even when compared to triple-glazed windows[16]. Liang et al. conducted a simulation study to evaluate the performance of thermochromic glasses in five different climatic regions of China. The study examined the operating temperature range of 20°C to 41.3°C and the solar transmission factor range of 0.412 to 0.690. The results showed that: 1) A moderate modulation of solar transmission is more suitable for most climatic conditions, and low transfer temperatures are not necessary to maintain the building's energy. 2) Higher solar absorption can improve thermochromic glass's performance, but it may also increase the heating of the window. 3) All the thermochromic windows evaluated showed energy savings in the building, with a maximum of 19.9%, and are suitable for use in hot climates[17].

Liang et al. investigated the effect of combining vanadium dioxide and iron-liquidbased thermochromic windows in different climates in China. They found that the performance of the combined windows is strongly influenced by the regional climate conditions[18]. Giovannini et al. evaluated the effect of Low-emissivity Electrochromic Technology (LETC) on the energy efficiency of buildings. They developed a framework for evaluating the performance of other switchable glazing technologies based on their findings on LETC[19].

In their review of articles and research on thermochromic glasses from 2009 to 2019, Aburas et al. found that thermochromic windows can save heating and cooling energy by 5.0% to 84.7% compared to conventional glass, depending on the climate. The energy-saving performance varied by location and type of glaze, with differences between cities using the same type of glaze up to 73.4%, and much less difference between different types of glazes used in the same city, up to 21.6%[20]. Salamati et al. utilized the sol-gel method to produce a novel nanoparticle structure with both thermochromic and photocatalytic properties by doping tungsten ions (W^{6+}) on a vanadium dioxide film and adding titanium dioxide (TiO_2) to the solution. They evaluated the energy-saving potential of the produced thermochromic (TC) glazing compared to standard products by simulating a model of a room in a residential building using EnergyPlus software. The simulation results demonstrated that the fabricated TC glazing could significantly reduce the energy demand of buildings compared to current approaches[21]. Hu et al. conducted a study comparing common roofs to thermochromic roofs and found that the latter can significantly reduce HVAC load demand, leading to savings of up to 40.9% in total energy consumption, 47.7% in energy cost, and 46.7% in energy-associated CO_2 emissions for buildings in San Francisco, CA. Compared to conventional cool roofs, thermochromic roofs offer additional benefits, reducing overall energy consumption by up to 7.7%, energy costs by 3.6%, and energy-associated CO_2 emissions by 28.5%. The study also highlights the importance of the geographic region in determining the effectiveness of thermochromic roofs[22].

In another study, Vuong et al. investigated the potential of integrating photovoltaic panels into the building's envelope, which is called Building-Integrated Photovoltaics (BIPV), as a way to reduce the building's energy consumption and provide clean energy. They compared the energy performance of a BIPV/T system modeled using EnergyPlus and TRNSYS software and found differences in results due to different sky temperature computations, electrical models, and weather data interpolation algorithms used by each software[23]. According to the study by Yanyi Sun et al., the use of thin-film CdTe solar cells with 10% transparency in a typical office building resulted in better daylighting performance compared to regular double-glazed windows. The study also showed that the system performed better in window-to-wall ratios of more than 45%. These results demonstrate the potential of integrating photovoltaic systems into building windows and other parts of a building to improve energy efficiency and daylighting performance[24]. Wenwen Guo et al. conducted a study to determine the optimal transmittance rate and orientation for photovoltaic (PV) windows to improve energy efficiency in 5 different climate regions in China. The results showed that higher transmittance rates lead to lower electricity consumption and that south-facing windows performed better than windows with other orientations in these Chinese cities. [25]. Ellen David Chepp et al. has recently focused on the effects of shading and panel orientation on the efficiency of photovoltaic (PV) systems. They found that losses are substantial if shading is parallel to the short edge of the panel. However, the losses are lower when shading occurs along the long edge. The orientation of the panel, either landscape or portrait, does not have a significant effect on energy efficiency according to their results [26]. In the study by Minjeong Sim et al., a Korean campus building was used as a case study to investigate the potential of decreasing its energy consumption through the integration of photovoltaic (PV) and ground-source heat pumps (GSHP). The study used EnergyPlus and Design Builder software and a multi-objective genetic algorithm to optimize the system's design. The cost of the applied optimization models was analyzed based on economic factors, and the results showed the type of building and the impact of the sales method on the sale of extra renewable energy produced. The study aimed to determine the feasibility of using renewable energy to cover the energy needs of campus buildings[27]. The study by Mun et al. aimed to investigate the limitations of EnergyPlus software in analyzing the energy performance of semi-transparent photovoltaics (STPV) modules used in building windows. The study compared the results of various simulations with a laboratory model and aimed to improve the algorithm for more accurate results by identifying the best algorithm. The findings of the study can help improve the accuracy of energy performance analysis for STPV modules in buildings[28]. In the study by Clara Good et al., the efficiency of using solar thermal systems and photovoltaic (PV) systems in near-zero energy buildings (NZEB) was compared with the design of hybrid photovoltaic thermal (PV/T) systems. The results showed that PV/T systems were more efficient, providing both hot water and electrical energy and taking up less space. The study was simulated on a building in Norway, and it was found that high-efficiency PV systems were the closest to satisfying the near-zero energy building requirements. The near-zero energy building (NZEB) efficiency is dependent on the building's energy design boundary conditions[29].

In recent years, there has been a growing interest in integrating passive and active technologies to reduce annual energy consumption in buildings. While many studies have investigated the efficiency of specific passive or active technologies or evaluated the performance of technologies for building components such as roofs or windows, there remains a research gap in exploring the individual impacts of these passive technologies on a unique building geometry. Additionally, it is rare for papers to aim to perform a simulation with accessible materials on the market.

In this study, we aimWindows to simulate a unique building geometry in the climate conditions of Tehran using accessible materials from the market. We will focus on three important passive technologies: roof vegetation, thermochromic windows, and smart blinds, and investigate the amount of annual energy consumption reduction. Our goal is to identify which of these technologies and their effective parameters are critical in achieving energy savings.

2. Methodology

2.1. Model specification

According to Fig. 1, the building used in this research to evaluate the effectiveness of passive technologies in reducing energy consumption was extracted as a two-story villa from the geometries available on the Sketchup website. The geometry of the villa was modified to meet the requirements of the research. The materials used in this study, as listed in Table 1, were chosen based on the national building standards of Iran and actual materials available in the market to ensure the results of the research are realistic. The building has two floors with a total height of 5.71 meters, with each floor measuring 2.80 meters in height. The length of the villa is 13.16 meters, and the width is 9.6 meters, with a total floor area of 106 square meters. A total of 52 windows, each with a width of 1 meter and a length of 2.18 meters, and one door were included in the design.

The use of a packaged terminal heat pump (PTHP) with both heating and cooling capabilities is preferred. As shown in Fig. 2, the chosen package in this study is of the electrical type that utilizes electrical energy directly to maintain the desired temperature. This package includes several sub-components, which EnergyPlus software allows us to select by default when selecting the desired living area. It is important to note that specific comfort temperatures have been established for specific hours of the day for heating and cooling purposes. For example, throughout the year, the heating setpoint from midnight until 6:00 AM is around 20.5°C, from 6:00 AM until 8:00 PM it increases to 22.7°C, and from 8:00 PM until midnight it decreases again to 20.5°C. Similarly, the cooling setpoint from midnight until 6:00 AM remains at 22.3°C, from 6:00 AM until 8:00 PM it increases to 25°C, and from 8:00 PM until midnight it decreases to 22.3°C.

Table 1. The specifications of building material

Component	Material	U-value
Exterior wall	Plaster(20mm) Gypsum mortar and soil(25mm) Leica Block(100mm) Fiberglass thermal insulation(50mm) Cement sand mortar(30mm) Brick(20mm)	0.503 W/m^2K
Roof	Plaster(10mm) Gypsum mortar and soil(20mm) Leica Block(200mm) Thermal insulation(40mm) Concrete(50mm) Cement sand mortar(20mm) Moisture insulation(10mm) Cement mosaic(20mm)	0.417 W/m^2K
Ground floor	Ceramic(20mm) Cement mortar(20mm) Thermal insulation(40mm) Cement sand mortar(20mm) Concrete(20mm) Leica Block(200mm)	0.437 W/m^2K

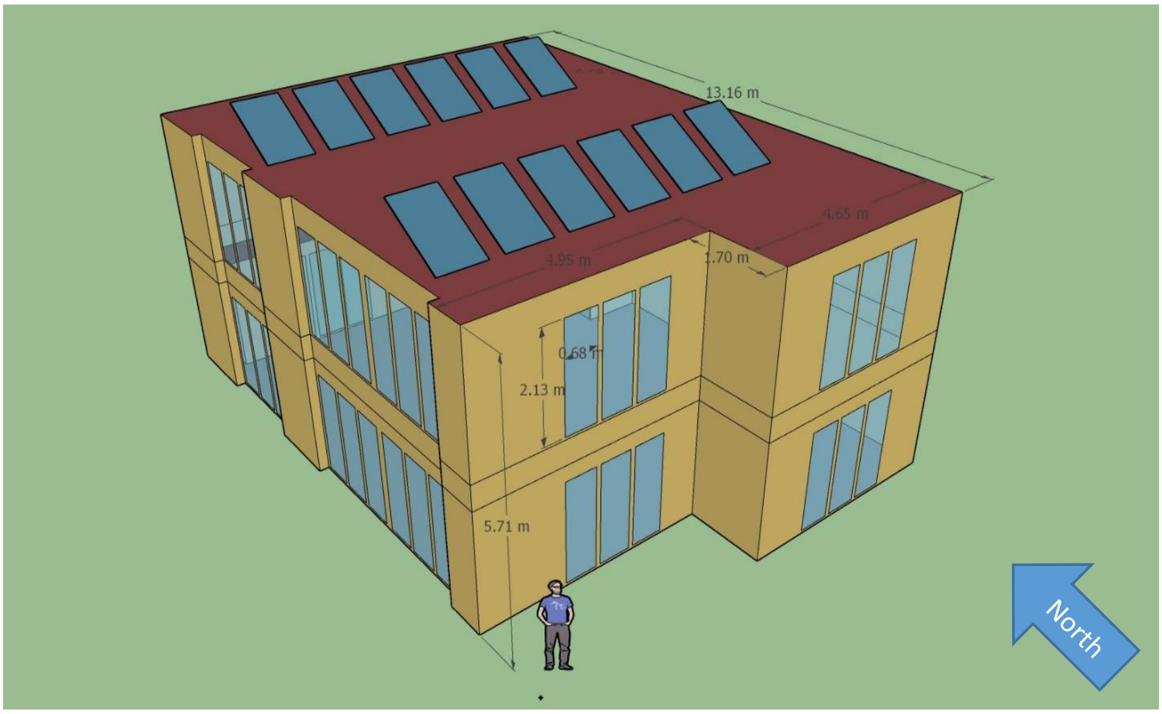

Fig. 1. The shape of the building model

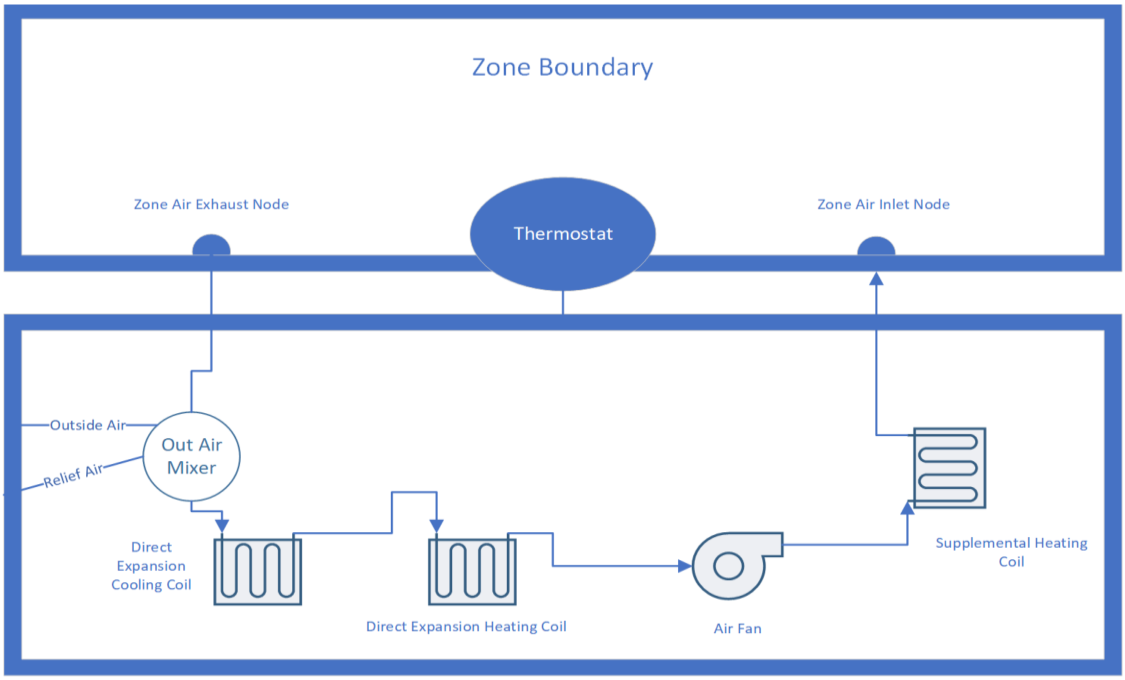

Fig. 2. Schematic of a packaged terminal heat pump (draw through fan placement)

The simulation of the building sets the required amount of light for artificial lighting at 15 watts per square meter. During nighttime hours of rest, these lights are turned off. The presence of residents, which affects energy consumption, is also taken into consideration in the simulation. The number of residents was set as four people with a variable presence at different times of the day. This presence was estimated using EnergyPlus software, expressed as a percentage. From 5:30 pm to 7:30 am, all residents are inside the building, while only 20% are present from 7:30 am to 5:30 pm.

2.2. Climate regions

In this study, the weather data of Tehran Mehrabad has been utilized. EnergyPlus provides more than 2,000 EPW files for different regions and cities globally. However, for Iran, climatic files are only available in seven cities including Tehran, Tabriz, Shiraz, Isfahan, Bandar Abbas, Kerman, and Yazd. These cities can be considered representative of different climates including hot and dry, hot and humid, cold and dry, and temperate climates. However, there are limitations in collecting and classifying this climate data. All of this weather data can be found on the EnergyPlus website.

2.3. Building energy simulation software

EnergyPlus is an all-inclusive building energy simulation software that allows engineers, architects, and researchers to model energy consumption in buildings for heating, cooling, ventilation, and water usage.

Some of the key features of EnergyPlus, particularly relevant to this study, are:

* Use of thermal equilibrium in calculating heat transfer effects from radiation and convection, resulting in surface temperature, thermal comfort, and condensation calculations.

* Adoption of a combined heat and mass transfer model that describes air movements between different spaces.

* Advanced window models, including smart window blinds, thermochromic glazes, and a layer-by-layer heat balance calculation to determine the amount of solar energy absorbed by windows.

* Precise output reports, along with user-defined reports with a selectable time resolution ranging from one year to one hour.

The US Renewable Energy Lab created software to enhance the user experience of EnergyPlus, a building energy simulation software used by engineers, architects, and researchers to model energy consumption. One of these softwares is Windows, where the user can design windows with full details such as the size, material, and shading type. The software offers a variety of standard glass options with physical and commercial specifications, making it easier for the user to design their building details. In the field of building design and 3D modeling, Google SketchUp is a powerful software that is highly favored for its ease of use compared to other design software that can be challenging. Its compatibility with the IDF format allows for seamless integration with EnergyPlus, enabling users to save their geometry design in an accepted format for EnergyPlus and make changes in the EnergyPlus environment. The resulting differences can then be viewed directly on the SketchUp file. SketchUp's integration with EnergyPlus is further enhanced through the OpenStudio plug-in. OpenStudio is a software tool for conducting more in-depth and advanced analysis of natural light in buildings. With its use, the building's design can be viewed from various angles, and the interior environment can be visualized. Additionally, the building's geographical orientation can be analyzed and modified if needed.

2.3.1. Thermochromic glasses

In this study, thermochromic glasses were utilized to reduce energy consumption. These glasses respond to temperature changes and darken when exposed to heat, thereby reducing the amount of sunlight entering the building. Table 2 lists the specifications of various actual models of thermochromic glass obtained from the Window software.

2.3.2. Green roof

In this research, vegetation is used as an energy-saving tool on the roof of the study's geometry. By adjusting factors such as height, density, and soil height, heat transfer can be reduced. The soil's physical characteristics play a crucial role in the effectiveness of the green roof, including conductivity, dry soil density, solar absorption rate, and specific heat. These parameters should be carefully considered for optimal results.

2.3.3. Shading control (using Exterior Blind type)

This study also employs the ExteriorBlind as a passive system to minimize building energy consumption. The ExteriorBlind is designed to significantly reduce heat transfer through windows. The shading control section in the study defines nineteen modes of using the ExteriorBlind in various conditions, each having distinct impacts on energy consumption.

3. Results and Discussions

3.1. Green roofs

The energy consumption of a building was compared for different values of the dry soil conductivity parameter in this study. Figure 3 depicts the results obtained by varying the dry soil conductivity parameter in the range [0.2, 1.5] with an increment of 0.05. As shown in the figure, the general trend of the diagram decreases in the range [0.2, 0.65], with the lowest annual energy consumption of 8731.396 kWh occurring at 0.65. An upward trend occurs at 0.7 and a descending trend resumes until 1.3, where the trend changes slightly upward again. In the range [1.35, 1.5], the descending trend resumes. Results show that 93% of the annual energy consumption, which is primarily used for cooling, is due to the building's shape, construction materials, and location in Tehran with its hot weather. These percentages and the general decreasing trend of the diagram suggest that the building needs more heat exchange from the roof to reduce energy consumption. However, at 0.65 and 1.3, this equilibrium changes. Thus, using this parameter optimally can decrease annual energy consumption by approximately 2.13% per year.

Table 2. Specification of Thermochromic glasses

ID#	Product Name	Name	Manufacturer	Conductivity	Type	Thickness
30010	Thermochromic1_24	Thermochromic1_24.LBL	LBNL	1w/m.k	Thermochromic	7 mm
30020	Thermochromic2_24	Thermochromic2_24.LBL	LBNL	1w/m.k	Thermochromic	12 mm
30030	Thermochromic3_24	Thermochromic3_24.LBL	LBNL	1w/m.k	Thermochromic	12 mm

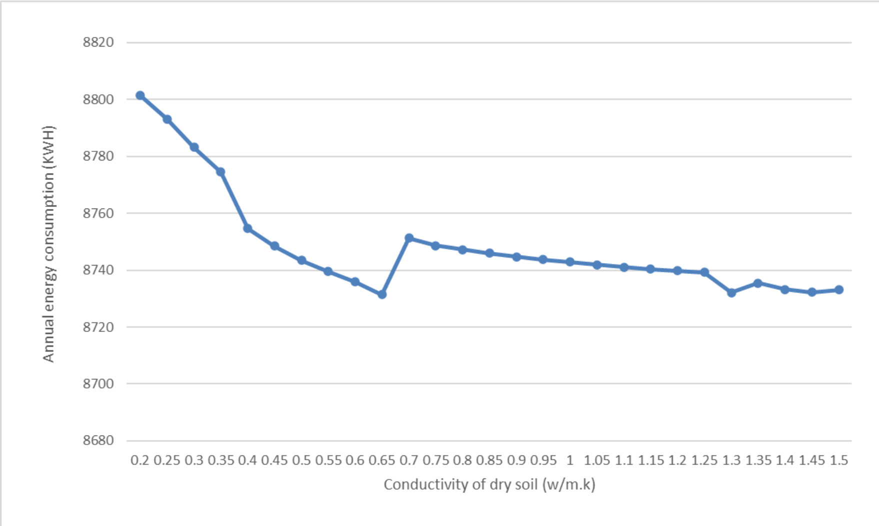

Fig. 3. Effect of conductivity of dry soil on annual energy consumption

Figure 4 illustrates the annual energy consumption of the building for varying solar absorption parameters in the range of 0.4 to 0.9, with an interval of 0.1. As depicted in the figure, the overall trend of the diagram is upward, indicating that in this particular building with its specific shape and material, the lowest annual energy consumption occurs at a solar absorption value of 0.4, with a total of 8713.4 kWh per year. Given the abundant hot and sunny days in Tehran, it is advisable to minimize the solar absorption from the roof. This analysis suggests that by optimizing just this parameter alone, the annual energy consumption can be reduced by approximately 2.34%.

The annual energy consumption of the building for different values of the dry soil density parameter is compared in Fig. 5. The values of the density parameter used in this diagram range from 300 to 2000 with a step of 100. As shown in the figure, the general trend of the graph is decreasing, with the lowest annual energy consumption occurring in 2000 with an amount of 8719 kWh. The trend in Fig. 5 is quite similar to Fig. 3, suggesting a relationship between dry soil density and conductivity. The diagram in Fig. 5 reveals different behavior at two points, 1000 and 1900, which could be attributed to the building's shape and location's weather conditions. This analysis suggests that optimizing just this parameter could result in a decrease in annual energy consumption by around 2.3% per year.

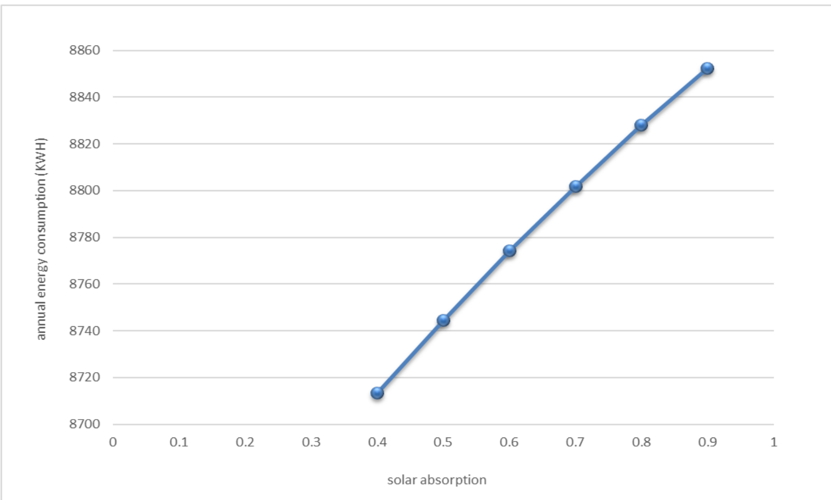

Fig. 4. Effect of solar absorption on annual energy consumption

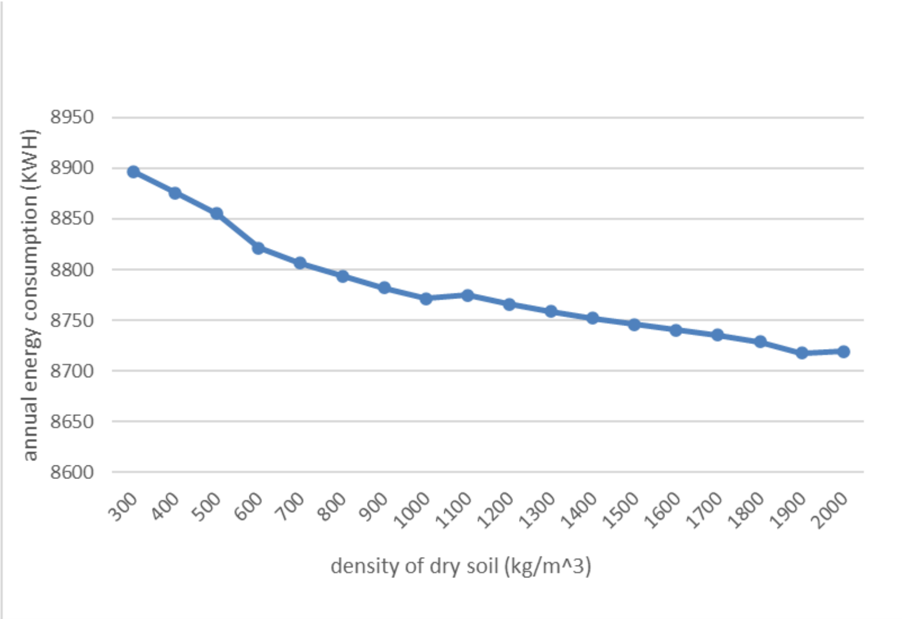

Fig. 5. Effect of density of dry soil on annual energy consumption

Figure 6 shows the impact of different values of the specific heat of the dry soil. This comparison is made in the range of [1200, 2000] with an increment of 100. As depicted in Fig. 6, the overall trend of the diagram is descending, and at the value of 1900, the lowest annual energy consumption occurs, amounting to 8766 kWh. The trend in Fig. 6 suggests that as the specific heat of the dry soil increases, which means it is better able to resist temperature increases, the annual energy consumption decreases. In other words, the building needs to reduce heat transfer from the roof. It's worth noting that the general behavior of the diagram changes at two points, 1300 and 2000, which may be due to the complex circumstances of the building. This analysis implies that using this parameter at its optimal point alone can decrease annual energy consumption by approximately 1.75%.

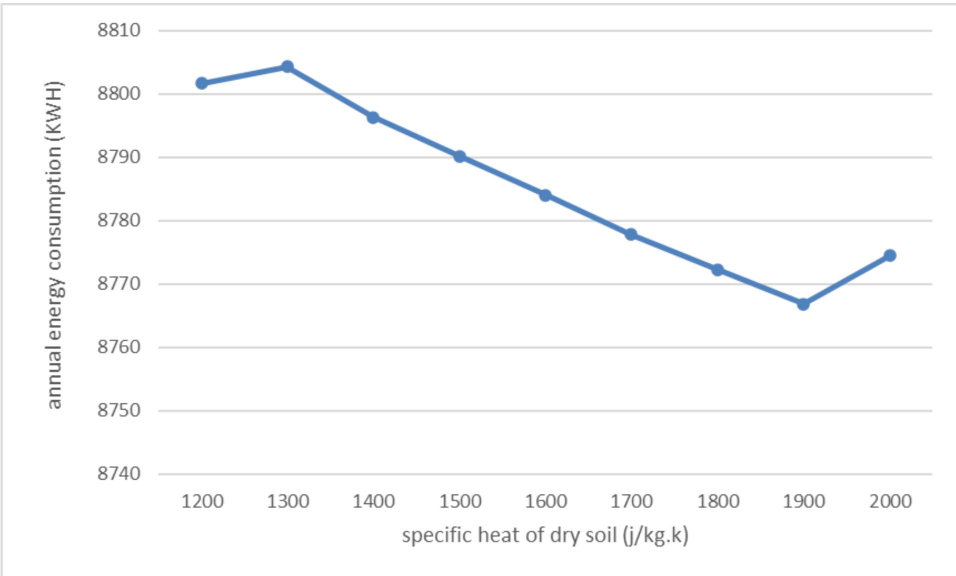

Fig. 6. Effect of Specific heat of dry soil on annual energy consumption

3.2. Thermochromic glasses

The line charts in Figs. 7, 8, and 9 demonstrate the monthly energy consumption of the building when using different types of thermochromic glasses. It is evident from the charts that heating and cooling loads vary based on the seasons. The charts also reveal new insights into the impact of windows on annual energy consumption. For instance, Figs. 8 and 9 indicate that 38.2% of yearly energy consumption is for cooling and 61.8% is for heating. This comparison highlights the extent of heat loss from windows during cold seasons. Additionally, the use of thermochromic glasses reduces the amount of solar heat entering the building during hot seasons, which leads to a lower cooling load compared to the heating load throughout the year.

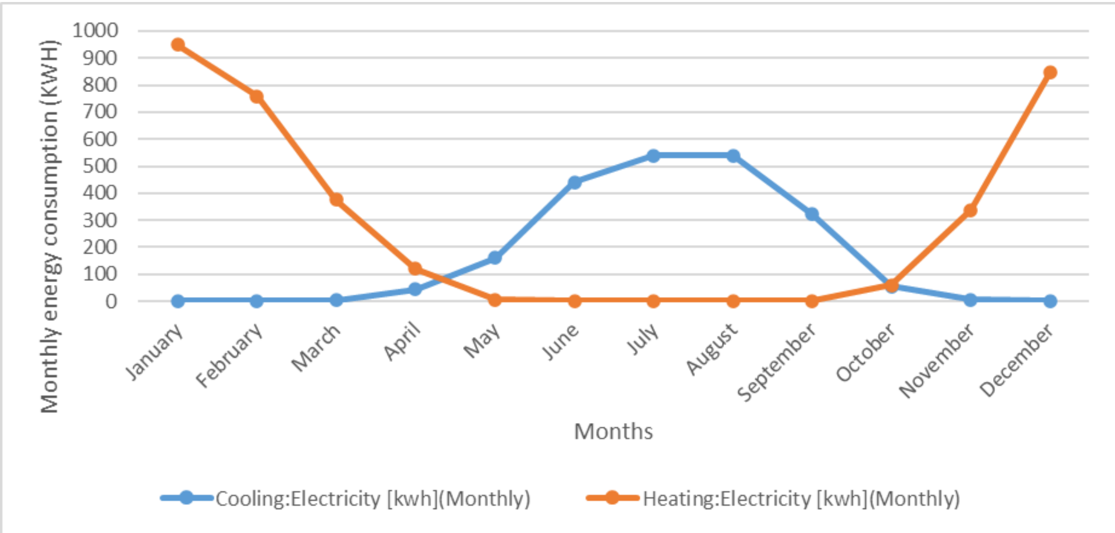

Fig. 7. Monthly energy consumption diagram using thermochromic1_24.LBL

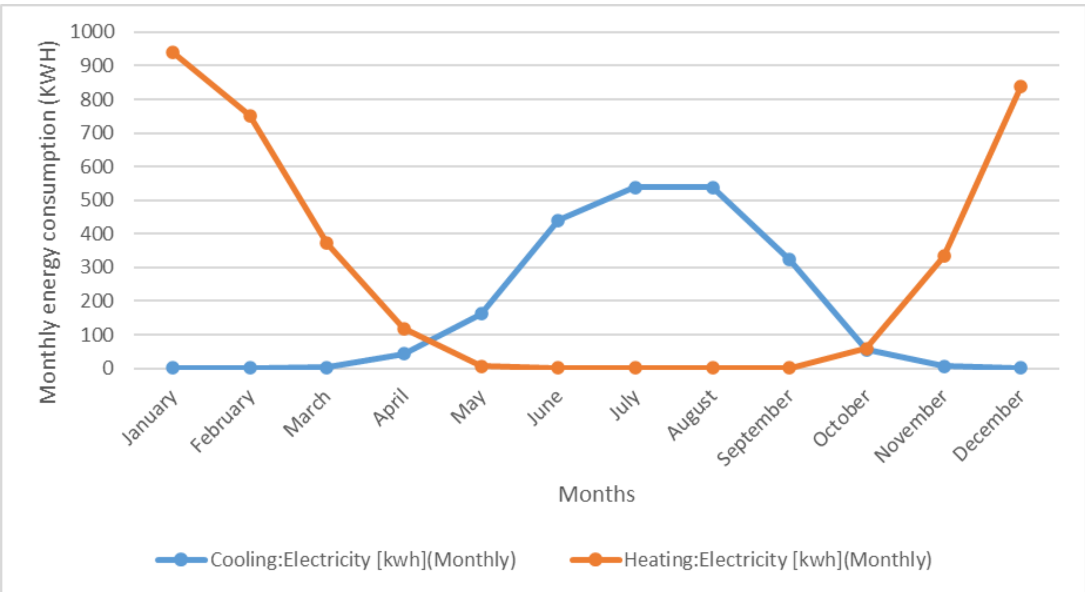

Fig. 8. Monthly energy consumption diagram using thermochromic 2_24.LBL

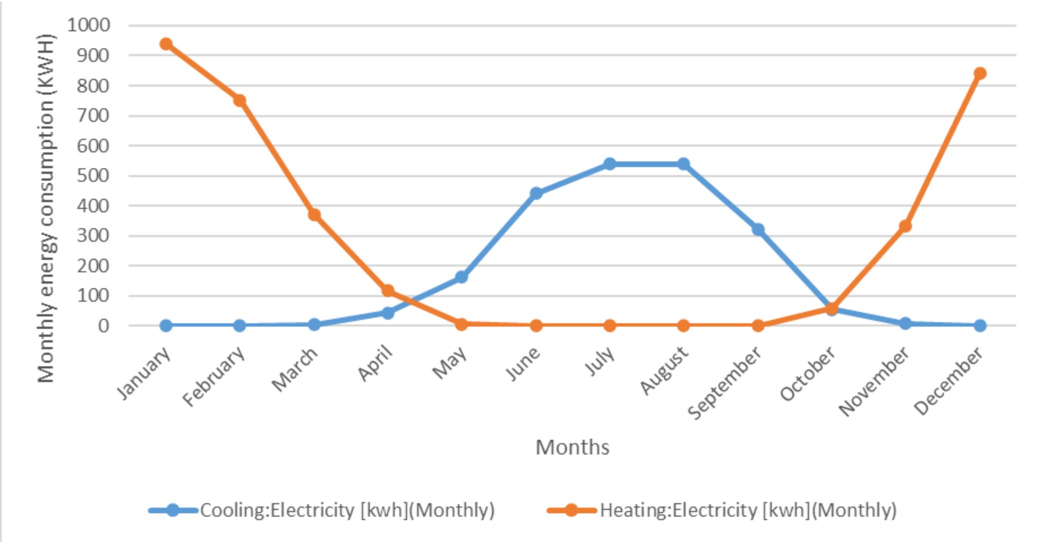

Fig. 9. Monthly energy consumption diagram using thermochromic 3_22.LBL

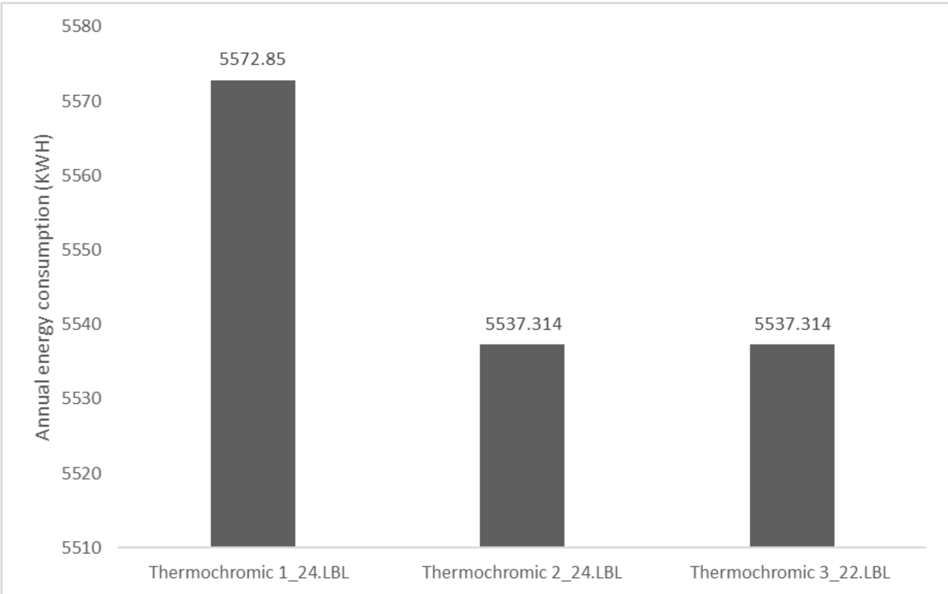

Fig. 10. Annual energy consumption by using different Thermochromic glasses

Figure 10 displays the annual energy consumption of the building when using different models of thermochromic glass. The comparison between the three models reveals that as the thickness of the thermochromic glass increases, the annual energy consumption decreases. Ultimately, it can be concluded that by using the thermochromic 2_24.LBL and thermochromic 3_22.LBL models, the annual energy consumption can be reduced by approximately 37.94%.

3.3. Exterior blinds

This section presents the annual energy consumption of a building using different scenarios for exterior blinds, as shown in Fig.11. It is evident from the figure that of the five conditions (always off, on if high glare, on the night if low temp out off day, on the night if low temp inside off day, on the night if heating off day), none have a significant impact on the annual energy consumption. However, under two conditions (if high solar on the window, on if high horiz solar), the decrease in annual energy consumption is approximately 37%. This result suggests that these conditions are considered equivalent to EnergyPlus software and highlight the prevalence of sunny weather in Tehran. In two other conditions (on if high zone air temp and high solar on window, on if high zone air temp and high horiz solar on window) the amount of decrease in annual energy consumption is about 37%. and the results indicate that these conditions, according to the building's location and circumstances, mean the same to EnergyPlus software, and on the other hand, it shows that Tehran's weather is mostly sunny.

The two additional conditions (high outside air temperature and high solar on window, high outside air temperature and high horiz solar on window) result in a decrease of around 38% in annual energy consumption. The results show that these conditions are interpreted similarly by EnergyPlus software, regardless of the building's location and circumstances. Furthermore, it highlights the predominantly sunny weather in Tehran.

In various conditions, the rate of decrease in annual energy consumption of the building is shown:

*On if high outdoor air temperature: 40% reduction

*On if high zone air temperature: 39% reduction

*On if high zone cooling: 55% reduction

*On night if low outdoor temperature and on the day if cooling: 56% reduction

*Always on: 39% reduction

*Off night, on the day if cooling and high solar on the window: 56% reduction

*On the night and day if cooling and high solar on the window: 56% reduction

These results indicate the effect of using exterior blinds on reducing annual energy consumption, based on the building's location and circumstances as evaluated by the EnergyPlus software.

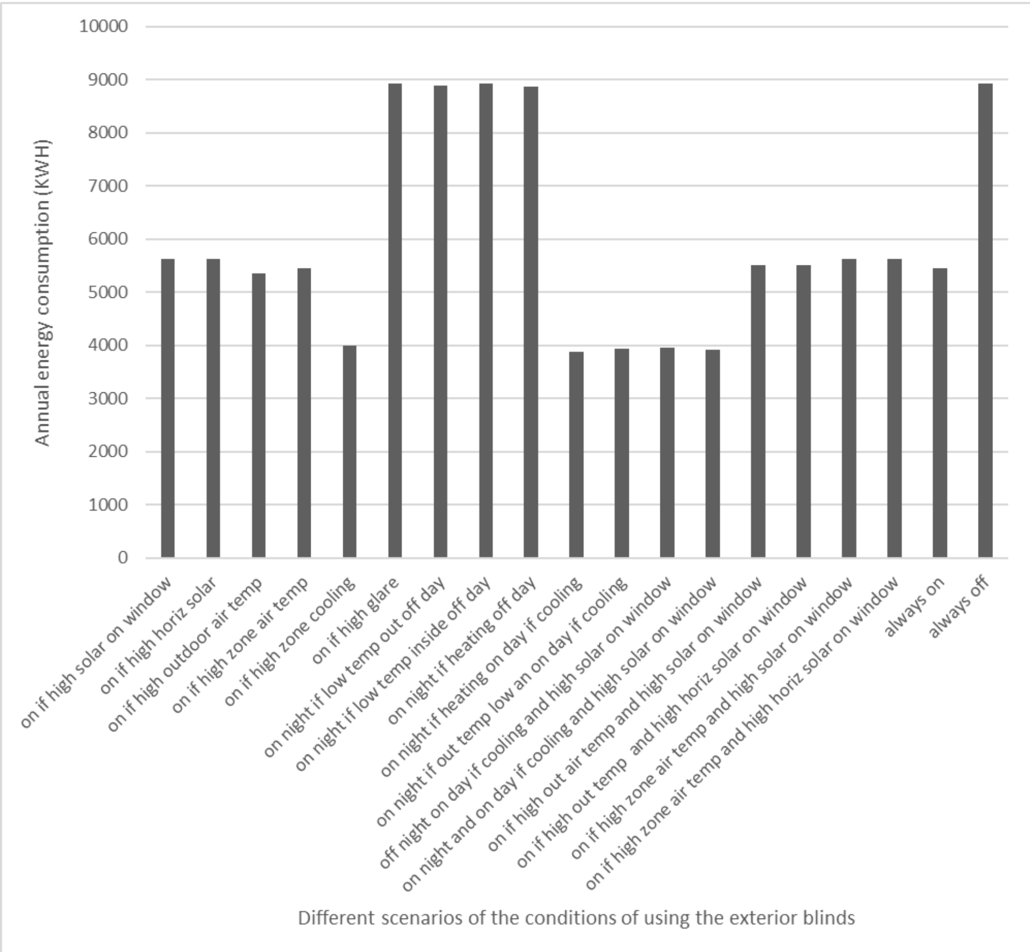

Fig. 11. Different scenarios of the conditions of using the exterior blinds

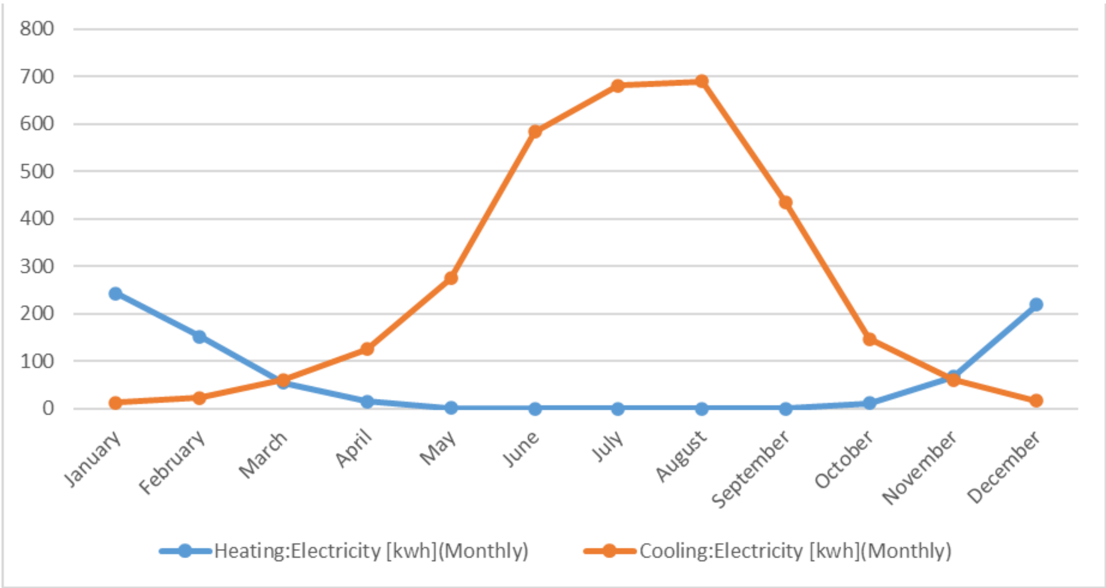

Fig. 12. On the night if heating, on the day if cooling

According to the chart, the scenario with the least annual energy consumption is "on the night of heating and the day of cooling." In this scenario, the annual energy consumption is approximately 3879.903 kWh, and the reduction in annual energy consumption is around 56.5%. Figure 12 is a line chart that depicts the building's monthly energy consumption in this scenario. It's evident from the chart that utilizing exterior blinds optimally can significantly reduce heating loads.

4. Conclusion

In this final section, we present the findings of our study and provide recommendations for further improvements. Our research focused on evaluating the effectiveness of passive technologies in a specific building geometry in the climate of Tehran. Specifically, we aimed to determine the critical parameters that contribute to reducing annual energy consumption using real accessible materials in our simulation. In the analysis of the impact of dry soil conductivity on the building's energy consumption, values in the range of 0.2 to 1.5 were compared at increments of 0.05. The results show that as the value of the parameter increases, the building's energy consumption decreases, reaching a minimum of 8733.063 kWh. This decrease represents a reduction in energy consumption of 2.13%. The diagram indicates a general trend that higher dry soil conductivity leads to lower energy consumption for the building. The trend depicted in the diagram shows that a higher thermal conductivity of dry soil in the green roof results in a decrease in annual energy consumption. Another part of the study analyzed the effect of dry soil density on the building's energy consumption, with values ranging from 300 to 2000 in increments of 100. The lowest annual energy consumption was observed at a soil density of 2000, leading to a reduction of 2.3%. The chart indicates that increasing the density of soil used in green roofs leads to a reduction in energy consumption. The chart of the impact of solar absorption shows that the lowest annual energy consumption of the building occurs when the solar absorption value is low. Specifically, at 0.4, the energy consumption is 8713.4 kWh, which represents a 2.34% decrease in the building's annual energy consumption. The trend displayed in the chart suggests that a lower amount of solar radiation absorption for the dry soil used on the green roof results in lower annual energy consumption for the building. In another comparison of the green roof parameters, the specific heat of the dry soil was studied in a range of 1200 to 2000 with a step of 100. The chart shows that for a specific heat of dry soil of around 1900, the lowest annual energy consumption is 8766.883 kWh, indicating a decrease in building energy consumption of 1.75% per year. The general trend indicated by the chart is that the higher the specific heat of the dry soil used in the green roof, the lower the annual energy consumption of the building. In the examination of the impact of different models of thermochromic glasses on reducing the building's annual energy consumption, it was found that the use of models 3_22 and 2_24 decreases energy consumption by 37.94%. It is noteworthy that the only factor that influences the difference in energy savings among the thermochromic glasses is their diameter. The results from the shading section reveal that there are 19 ways to use exterior blinds. Upon comparison, it was found that the use of exterior blinds has the greatest impact during the day, and the direction of sunlight does not affect energy consumption in the geometry and climatic conditions of this study. The "on the night if heating, on the day if cooling" mode has the highest energy savings, with a saving rate of 56.51%.

The results suggest that the use of smart exterior blinds has the greatest impact on reducing energy consumption, followed by the use of different models of thermochromic glass, and finally, the implementation of green roofs. These findings highlight the potential for energy savings in buildings through the use of advanced technologies and materials.

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