ICONARP
International Journal of Architecture and Planning
Received: 17.03.2023 Accepted: 29.11.2023
Volume 12, Issue 1/ Published: 30.06.2024
Research Article *DOI: 10.15320/ICONARP.2024.282 E- ISSN:2147-9380*
ICONARP

Optimizing Passive Strategies for Energy Demand Reduction in Cold Climate Residential Buildings: A Case Study in Tabriz, Iran

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Abstract

The fast growth of the population is leading to an ever-increasing trend in energy consumption these days. In this regard, the construction industry is among the biggest consumers. Considering that most buildings are residential, energy optimization is essential, especially during the initial design phase. A practical way of building design with less energy demand is passive design methods. The importance of this issue is more visible in residential buildings in cold climates, which have the greatest temperature fluctuations. This study aims to investigate the energy demand of different passive strategies applied to a residential building in the cold climate of Tabriz, Iran and to select the most efficient design factor. The methodology is a combination of qualitative and quantitative methods. As the first step, considering the theoretical framework of the research, passive systems and the factors affecting building envelope thermal performance are determined. In the next step, EnergyPlus is used to analyze the application of the passive systems in the baseline model. All states are simulated separately in terms of the amount of heating and cooling energy demand and the results are presented in compareable graphs. In the third step, the strategy that has the greatest impact on reducing energy demand in cold-climate buildings is identified, and the most efficient alternative is presented through the analysis of different scenarios compared to the baseline model. This research reveals that heat loss through the envelope accounts for most of the energy demand, and thermal insulation plays an important role in reducing that loss. Also, different scenarios (materials, thickness and location) of thermal insulation were investigated. It shows that the optimal mode of thermal insulation in residential buildings in cold climates is to use polyurethane insulation with a thickness of 7 cm in the outer part of the building wall.

Keywords:
Cold climates, Energy demand, EnergyPlus, Passive strategy, Thermal insulation

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To cite this article: Ghouchani, M., & Todeh Kharman, H. (2024). Optimizing Passive Strategies for Energy Demand Reduction in Cold Climate Residential Buildings: A Case Study in Tabriz, Iran. *ICONARP International Journal of Architecture and Planning,* 12 (1), 211-233. DOI: 10.15320/ICONARP.2024.282

INTRODUCTION

Energy is one of the main production elements among all economic sectors, significantly affecting the economy (Ghanbari et al., 2018). Global research indicates that energy consumption is a major factor in countries' rapid economic and industrial development. Moreover, energy has the largest share in global activities and trades. Choosing the energy type depends on the country's policies. For example, France produces most of its energy (about 75%) from nuclear power plants, while countries like China and the United States of America depend on coal and oil to meet most of their energy demand, 65.2% and 37%, respectively (Abbasi Godarzi & Maleki, 2017). Due to the adoption of strict environmental laws and energy crises, developing renewable energy in developed industrial countries is important. Renewable energies are environmentally friendly and economically more affordable than fossil fuels. Wind, solar, hydroelectric, and geothermal energy are the most important renewable energies, and they have an ever-increasing usage speed (Sarleki & Hasan-Beigi, 2018).

Until recently, fossil fuels were one of the most popular energy resources worldwide and were preferred to other energy resources. However, the disadvantages of excessive use of these fuels have led people to look for other energy resources and ways to reduce energy consumption. Fossil resource limitations, environmental concerns, and political and economic crises have made energy management a priority. (Maftouni and Motaghedi, 2020). Population growth has increased energy demand in the building sector, which is expected to continue. According to statistics published by various organizations on energy consumption in different sectors, including the International Energy Agency (IEA), about 30% of global energy is consumed in the residential and commercial sectors. Heating and cooling in buildings consume a large portion of this amount (Bravo Dias et al., 2020).

Also, investigating the effect of climate change on energy consumption is becoming a special issue for economists and policy makers. Many believe that climate change is affected by human activities and energy consumption, especially fossil fuels (Ansell & Cayzer, 2018). Meanwhile, the effect of energy consumption on climate change is interpreted with concepts such as the effect of greenhouse gas (GHG) emission (Taherifard Hanjani & Mirhashemi Dehnavi, 2021). In addition to the air temperature rise, GHG emissions are increasing, making it more important to use less energy and be more energy efficient. (Wesseh Jr & Lin, 2018).

Passive systems use renewable energy and natural resources in various climates, using the building elements as design solutions (Zhang et al., 2019). As the problems of rapid urbanization increase, sustainable approaches have become a priority in the policies of developed countries. Developing countries like Iran are now following these policies to solve various cultural, social, and environmental problems while considering their economic consequences (Fakhar Asfarizi and Gandoomakar, 2020). By designing passive buildings, energy savings can be achieved by

DOI: 10.15320/ICONARP.2024.282

adjusting the form and orientation, the layout, the selection of the best envelope for climate conditions, fenestration sizes according to solar heat gain and loss, glazing types, and implementing appropriate methods to replace fossil fuels with renewable energy (Jomehzadeh et al., 2020). Despite their differences, each of the above reduces the building energy consumption to some extent. The factors discussed in the design process should be evaluated and prioritized according to their effect on energy consumption.

Iran consumes approximately 9% of the world's petroleum products while having only 1% of the world's population (Akbari Paydar et al., 2019). Over the last few years, the global energy consumption has increased by approximately 1-2 % annually, while Iran's consumption has increased by approximately 5%-8% per year (Mansouri and Heidari, 2021). In other words, energy consumption growth in Iran has risen more than five times the global average and annual energy subsidies of $1-$3 billion are paid. Studies indicate that if the trend continues, by 2030, Iran will become a petroleum importer (Fathalian and Kargarsharif, 2020). According to Iran Energy Balance data, in 2012, the share of the building sector (residential, industrial, and commercial) in the total final energy consumption in the country was 36%, which shows the importance of this sector in total energy consumption (Fayyaz et al., 2021).

As living standards have improved, the desire for comfort has also increased. People want to feel comfortable wherever they are. Thermal comfort conditions vary from person to person and from region to region. Such regional differences have a significant effect on energy consumption. If the indoor temperature of buildings in hot areas is supposed to be 25 degrees Celsius in winter, 20 degrees is enough in cold areas (Balilan Asl et al., 2021). Every one degree change in heating and cooling systems reduces about 7% of energy demand in the building (Shabanian et al., 2021). In the temporal analysis of thermal comfort for the cold climate of Tabriz city, based on Ashrae standard 2004-55, summer has the highest seasonal comfort 64% of the time (Qavidel Rahimi & Ahmadi, 2013). In Tabriz, during November to April, in addition to passive measures, active heating measures are also necessary. In the hot months of July and August, thermal comfort can be achieved by passive systems. In other months (September, October, May and June) the weather conditions of Tabriz are within the comfort range (Sabouri & Rahimi, 2017). So, a large amount of energy consumed by residential buildings in Tabriz is used for heating, and reducing the energy consumption in this climate depends on reducing the heating load.

Considering the importance of the subject, i.e. providing comfortable user condition in the cold climate, the aim of this research is to investigate the energy demand of residential buildings in different design conditions in cold climate of Tabriz. Reducing heating load is prioritized in cold climates for economic, energy security, and environmental reasons. Therefore, an effort has been made to calculate the amount of energy saved in each stage by measuring different strategies, and by changing these factors, the most optimal mode is selected. In this regard, by using simulations and quantitive analysis, the current study seeks to answer the following questions:

Which type of passive system has the most impact on energy demand?

What is the optimal state of this system?

RESEARCH BACKGROUND

Determining the range of thermal comfort in different climates with different models, including the "Olgyay" model and the "Terjong" model, relying on the influencing factors: temperature, radiant temperature, Humidity, air flow, activity rate, and clothing rate have been the subject of research by many researchers (Rezazadeh, R., & Aghajan Beiglou, 2012). Also, some critics have researched passive systems such as Trombe wall, solar space, and roof pond and their role in creating suitable thermal conditions in architecture (Abol-Hasani et al., 2022). The thermal performance of a building can be evaluated on three scales: micro-scale, medium-scale and macro-scale. Many studies are conducted on all three scales, yet they focus on the micro-scale and rarely consider the thermal performance of a building on a medium or macro-scale (Woo and Cho, 2018).

Mortezai et al. (2017) observe a strong correlation between primary energy consumption and plan layout, building location and form, building height, and open space area. They also observe a moderate correlation between primary energy consumption and building ratios. Haghani et al. (2017) investigated the effect of blinds on energy savings and discovered that blinds positively impact the total building loads. Ansarimanesh et al. (2019) used Design Builder simulator software to determine the optimal direction of an office building in Kermanshah. For this purpose, a frequently repeated type of office building in this city was simulated in the desired software with characteristics close to reality, and then the initial energy required for the building was calculated in different directions. The results of this research showed that considering the energy consumption index, the west-east stretch is the best orientation in the office buildings of Kermanshah.

Nourivand et al. (2021) studied the building energy performance simulation and optimization tools in the three main evolutionary stages of building energy performance: "design stage", "construction stage" and "operation stage". Reducing the energy consumption of an office building in the cold climate of Tabriz. In the article by Abdul Khaleqi et al. (2021), the effects of different criteria of solar greenhouse on the amount of energy intake and reduction of energy waste are presented. To achieve the desired goals, models of a residential unit with a solar greenhouse were examined with changes between the models. Ebrahimzadeh and Nilfroshan (2023) while calculating the angle of solar radiation in summer and winter and the degree of its rotation in the plan and section of tall residential buildings in Ardabil (cold climates), obtained the optimal form in such a way that the maximum area faces the sun in winter

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and have the least area facing the sun in summer. The results of this research state that by knowing the indicators of architectural form that are effective on energy consumption and efficiency in high-rise residential buildings in cold climates, it is possible to determine the level of energy efficiency from the perspective of physical and environmental indicators.

Ghadiri Moghadam et al.'s (2019) research, during laboratory and field studies, measured the amount of energy supply in five different modes from the combination of the Trump wall and the greenhouse phenomenon with the desired chamber in the first and second six months of the year in the cold climate of Ardabil city. The results of this research showed that among the different options of using the Trumpet wall and the greenhouse effect, installing the Trumpet wall and shade along with suitable windows on the south wall of the building with a score of 25.83 has the best performance in energy supply.

The purpose of this study is to evaluate the effect of several passive strategies step by step to determine which one has the most impact on the energy loads of a residential building in the cold climate of Iran. These include changing the glazing and window frame, shading, insulation, greenhouse, and orientations.

THEORETICAL FUNDAMENTALS

Passive systems are designed to meet buildings' heating, cooling, and lighting needs in a sustainable, climate-adaptive way while minimizing the use of HVAC equipment (Ghiabkloo, 2019).

Passive systems use architectural elements as design solutions for climate change. The passive system is nothing but the building itself. These building components will be effective in heating and cooling (Mashhor, 2019). Therefore, the use of passive systems requires careful design and decisions. Passive system elements are in full connection with the initial and basic architect design decisions, and after that, they are influential in the second stage of designing and organizing the form and shape of the building.

It should be noted that without observing the basic principles of climate design, applying these elements will not result in favorable performance. Using passive systems in a building may result in less energy consumption and lower costs of heating, cooling and lighting of the building. Furthermore, passive systems could create attractive and beautiful spaces, depending on the architect's ability (Vakilinejad et al., 2013).

These systems can be divided into passive heating and cooling systems. Passive heating is based on using solar thermal energy, and passive cooling is based on using different heat reducers (Vakilinejad et al., 2013). Considering the emphasis on the use of solar energy and reducing the consumption of fossil fuels, as well as reducing the costs of heating and cooling equipment and their repair, the role of these systems is important in achieving sustainable architecture.

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Using passive systems for heating and cooling buildings is not a new technique, and it has been used for centuries. Direct sunlight through a typical south-facing window is the simplest type of this system. Using solar heating in Europe did not begin until the 1920s (Safar Alipour and Shahgoli, 2013). During the late 1950s and the early 1970s, passive systems were believed to have the greatest potential for receiving solar energy. However, passive systems received more attention with the developments and the APEC oil embargo in 1973. Passive systems have a lower initial cost than active systems (Ghadiri Moghadam et al., 2019). They also require less maintenance and are more reliable.

A passive thermal system is a system in which the main elements of the building collect, store and redistribute solar energy. Passive heating is based on the use of solar thermal energy and passive cooling is based on the use of various heat reducers (Abdul Khaleqi et al., 2021). In a general classification, the types of passive solar systems can be classified as follows (Vakilinejad et al., 2013):

- Passive heating: direct absorption, thermal storage wall (Trump wall and blue wall), solar space (greenhouse and atrium), air transfer cycle (stone bed and double wall system)

- Passive cooling: cooling through ventilation (ventilation with wind power and chimney effect and night ventilation and wind ventilation cap and double-walled roof), evaporative cooling (direct and indirect), radiation cooling (direct and indirect), cooling through mass effect (direct and indirect connection), cooling through dehumidification

The use of passive systems in architecture has a long history. To create comfort in traditional houses, traditional architects have invented and used elements that are similar to the concepts of today's passive systems (Torabi, 2019). The use of passive systems in the architecture of traditional houses, while achieving stable thermal comfort in the house, has also provided reasons for moving in the direction of sustainable development and saving resources (Nazarboland et al., 2021). Passive heating is based on the use of solar thermal energy and static cooling is based on the use of air displacement and different heat reducers (Valizadeh Oqani and Movahedi, 2019). The native architecture of different regions has been formed in line with the climate of the region and in order to take advantage of the free energy of nature such as sun and wind, and they have tried to provide comfortable conditions for the residents of these buildings in the best possible way. The native architecture of the cold and mountainous regions of Iran is not exempt from this rule. In such a way that it is formed with the proper orientation and the way it is placed in relation to the sun, the ground and other factors, and on the other hand, by creating small openings and thick walls, we try to maintain comfort conditions inside the building and prevent the entry of factors that disrupt comfort, such as cold. have entered (Zarnashani Assal et al., 2019).

The traditional houses of Tabriz are used for the natural heating and cooling of the house by applying local climatic patterns and using clean

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energy such as solar energy and natural ventilation, and as a result, in addition to creating a balanced climatic environment, it has limited the consumption of fossil fuels. In a cold climate, reducing the heating load is prioritized in terms of economic and energy supply security and environmental pollution reduction (Ghoddosifar and Faramarzi Asl, 2022). In this regard, in order to achieve optimal thermal comfort in some cold months of the year, active measures are used to heat the architectural space (Ghafarigilandeh et al., 2019). Therefore, in order to facilitate heating in cold areas, large spaces are avoided, and different architectural solutions and patterns are used to heat the spaces in order to utilize natural energy. In the case of high heating needs, they use fireplaces (Zarnashani Assal et al., 2019). Considering that in a cold climate, most of the energy of residential buildings is used for heating, reducing the energy consumption of buildings in this climate depends on reducing the heating load of spaces (Ebrahimzadeh and Nilfroshan, 2023). Therefore, in the following, the solutions considered by the residents and traditional architects of Tabriz in order to take advantage of the static heating systems and deal with the climatic factors in line with the comfort and peace of the residents are presented:

Building orientation: The proper building orientation is one of the essential principles for the efficient use of natural resources and energy (Galal, 2019). The optimal orientation and placement of a building protects occupants from the cold winters and the hot summers and prevent entering unpleasant winds. In Tabriz, buildings are typically oriented to the south, with deviations to the east and west based on sunlight (Figure 1). In addition, cubic volumes, compacted design, and the use of shared walls reduce the external surface of the building and thus reduce the heat loss through the envelope. Meanwhile, the southern facade of the building faces the courtyard and receives sunlight without any obstruction (Xia and Li, 2019).

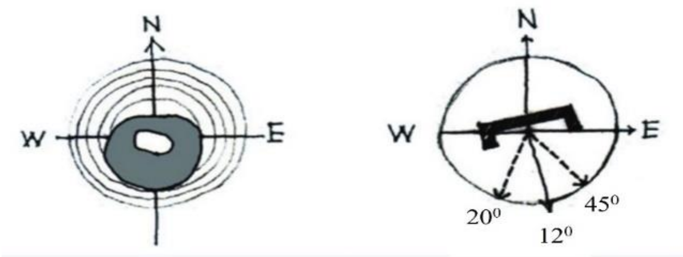

Figure 1. Diagram of Building orientation in cold climates (Ansarimanesh et al., 2019)

Earth coupling: Direct contact of parts of the building with the earth is one of the ways to reduce heat flow through the envelope; temperature is more stable underground than on the ground (Wang et al., 2020). Underground construction provides more thermal comfort in cold climates. Due to the high delay in the ground heat transfer, the ground's temperature is higher than the air temperature in winter and lower in summer, and the temperature fluctuations of the underground spaces are small (Yang and Jeon, 2020). Using basements and underground areas is one of the climatic strategies in Iranian architecture, which is also apparent in the traditional houses of Tabriz (Xia and Li, 2019) (Figure 2).

Figure 2. Placement of parts of the building in the soil in the house of Mojtahedi in Tabriz (Valizadeh Oqani and Movahedi, 2019)

Insulation: As a link between inside and outside, insulation in a building envelope is essential for reducing cooling and heating loads, improving thermal comfort, and saving energy (Liu et al., 2020). Insulation works as a shield between the inside thermal mass and the outdoors, which, in the winter, keeps solar heat inside the thermal mass during the day and returns it to the indoors at night. It also prevents sudden temperature rise during the summer. This function provides thermal comfort and reduces energy consumption, especially in winter.

Windows: Windows are one of the main elements of indoor space's cooling, heating and ventilation. Therefore, the key factors are window type, size, shape, configuration, and orientation (Fasi and Budaiwi, 2015). Traditional houses of Tabriz usually have south-facing windows, which provide more daylight and solar radiation. Also, the window height in the south is higher to increase sun access (Xia and Li, 2019). Skylights are another way to take advantage of daylight and natural ventilation in the houses of Tabriz (Haji Ghanbari et al., 2016).

Greenhouse: In cold climates and on the south side of buildings, sections with 100% glazing are designed to use solar energy. Sun rays enter through the windows and absorb into the walls and floors, which are typically dark (Han et al., 2021). The waves reflected from these surfaces have shorter lengths than the original, so glass blocks them. Thus, the sun's rays are trapped in the sunspace and gradually absorbed by different surfaces. The process heats the enclosed glass area and the surrounding spaces in cold climates (Esmaeli, R., Roshandel et al., 2020).

Natural ventilation: Creating airflow in the building for ventilation can be achieved artificially with devices like fan coils or naturally (Ghiyaee et al., 2013). Natural ventilation is a passive method of cooling and ventilating buildings that relies on natural forces, such as wind and buoyancy, to move air through indoor and outdoor spaces. By using this method, comfortable indoor conditions can be maintained without mechanical means in some periods of hot months.

RESEARCH METHOD

The present study aims to examine passive strategies based on a case study to reduce building energy demand with a qualitative and quantitative approach. Descriptive, analytical, and simulation methods are used throughout the research process. The case study enables us to

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conduct a comparative analysis of different passive strategies, allowing us to identify which strategies are more effective in specific contexts. This contributes to a nuanced understanding of the optimization potential. In this case, most of the simulations are on a single base room and there are some limitations to generalise them for larger areas with different layouts. However, it's crucial to emphasize that the selected building represents a complex typical case within a specific category (residential) in the selected region and as a result can be generalised for simillar places and buildings.

First, passive systems and factors affecting the thermal performance of external walls in a single-detached house are identified by studying the theoretical framework. The data collection consists of library studies, including thesis, articles, and searching about building materials in Tabriz.

Following that, simulations are conducted based on the findings and standard assumptions. Furthermore, simulations follow a clear pathway which is shown in flowchart below (Figure 3). It should be noted that scenarios are created at monthly intervals and the comparison is based on total annual result.

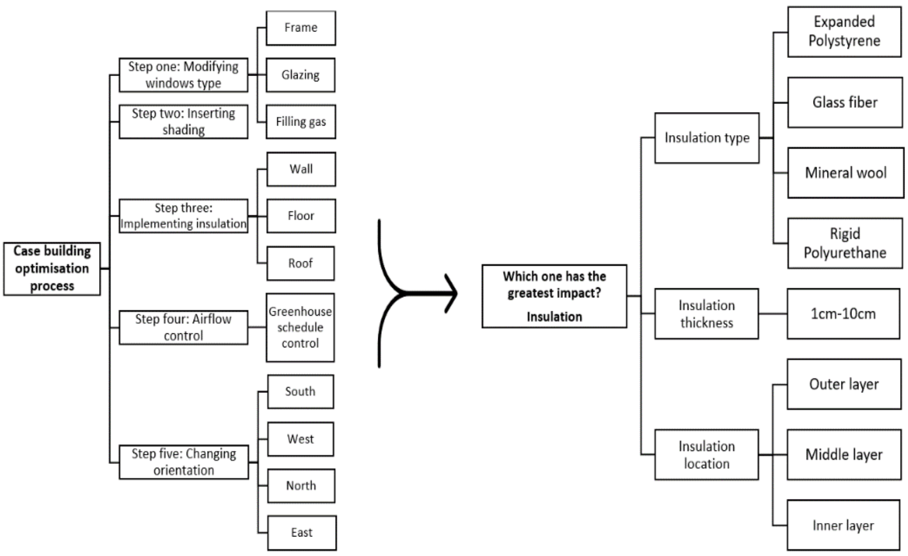

Figure 3. Case building optimization process flowchart

SketchUp is used to model the case building because of its specific features and user-friendly interface. Moreover, OpenStudio is used to determine the thermal zones of the building, fenestration, Window-to-Wall Ratio, and adjacency. Energy simulation is conducted by EnergyPlus (v. 9.2), which is a whole building energy simulation program that engineers, architects, and researchers use to estimate energy loads of heating, cooling, ventilation, lighting and water use in buildings (Bakhtyari, R., Fayaz, 2019). This software has been validated for energy building modeling in many studies before. For example, a practical way of validation is to collect real-world data in an experimental field work and collect simulation data based on realistic simulation and correct

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assumptions, and compare both results. This method has been shown in detail in some studies (Pereira et al., 2014).

Finally, the passive systems discussed previously are investigated, and the system with the highest impact on reducing energy consumption is proposed.

Region:

The studied city in the process of energy simulation is Tabriz, which is in northwestern part of Iran, and is located 38°5′ north and 46°16′ east. Its climate is classified as BSk by Köppen and Geiger, with harsh winters and hot, dry summers (Ouria, 2019). The ratio of comfortable hours to uncomfortable hours in Tabriz is about 7%, and creating comfortable conditions for human physiology requires energy (Ghobadian, 2021). Iran National Building Code considers Tabriz buildings high energy consumers and the cooling-dominant regions (Rouhizadeh, M. Farrokhzad, 2020). Dry bulb temperature and psychometric chart of the city are present, using the LadyBug plugin in Rhino in Figure 4, respectively.

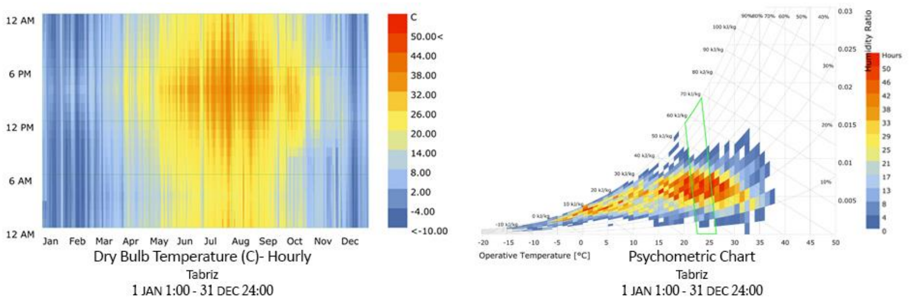

Figure 4. Left: Hourly dry bulb temperature, right: range of comfort conditions

The left side graph shows that the main heating period of the city is from November to March. However, on the other side, a small proportion (green line) of the whole year can be considered as a comfort zone and people do not need a heating or cooling system to feel comfortable.

Case building description:

The calculations were carried out on a simplified model of a two-floor building, including different parts which are shown in Figure 5.

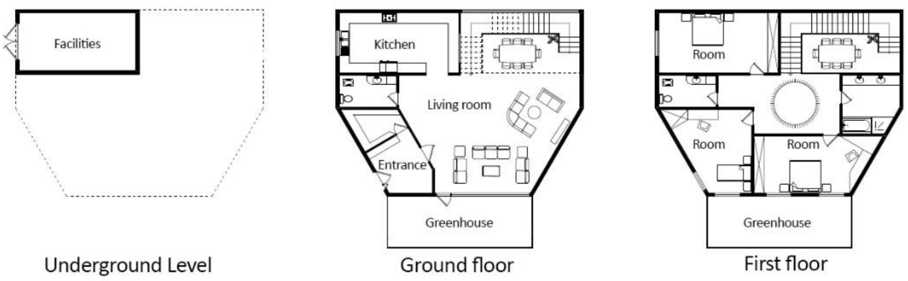

Figure 5. Layout design of the building

The total roof and ground slab surface is 140 m2, and the total area is 280 m2. In addition, the facility and greenhouse areas are 27 m2 and 25

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m2, respectively. In the southern part of the building, the walls are chamfered and do not follow a cube shape to get the maximum solar heat gain through the building envelope. Specifically, the building is south-oriented, with passive layout design principles. The living room, greenhouse and main bedrooms are in the south, corridors, stairs and kitchen in the north and other spaces in the east and west.

As a result of the sloped site, parts of the building, including the north and east walls on the ground level and portions of the first floor, are adjacent to the ground. Other outside surfaces have outdoor boundary conditions, and they define sun-exposed and wind-exposed surfaces. Other simulation assumptions on the case-building are provided in Table 1 and 2.

Table 1. Basic information about the case-building model

Title	Value
Total gross floor area	332 m^2
Number of floors	2
Floor-to-floor height	3 m
Building orientation	South-oriented
Terrain	Suburbs
Time steps per hour	6
WWR	S:40% N:20% W:30% E:0%
Glazing type	Single-pane clear with wooden frame
HVAC template	Ideal load air system

Table 2. Cross-section and physical properties of the construction of the case building

Construction Assembly	Elements from outside to inside	Thickness (m)	Thermal conductivity (W/m-K)	Thermal Resistance (m^2-K/W)	U-value (W/m^2-K)
Exterior wall cross-section	Cement board	0.03	0.58	0.052	4.103
	Cement plaster	-	-	0.026	
	Concrete 1600 (kg/m^3)	0.2	2	0.1	
	Gypsum plaster	-	-	0.066	
Interior wall cross-section	Gypsum plaster	-	-	0.066	2.592
	Brick	0.102	0.402	0.254	
	Gypsum plaster	-	-	0.066	
Roof cross-section	Asphalt	0.0032	0.04	0.08	2.627
	Cement plaster	-	-	0.026	
	Lightweight concrete	0.05	0.46	0.109	
	Concrete 1600 (kg/m^3)	0.2	2	0.1	
	Gypsum plaster	-	-	0.066	
	Cement	-	-	0.026	
Floor cross-section	Concrete 1600 (kg/m^3)	0.2	2	0.1	3.438
	Cement plaster	-	-	0.026	
	Laminated paperboard	0.01	0.072	0.139	

RESULTS

The approach of this study is to investigate the impact of various passive factors on the amount of cooling and heating energy demands in the building. It should be noted that while defining the case study may be simple as a strategy, its implementation is complex. In the process of using a case study, the reliability and validity of the process and the results achieved must also be analyzed. Moreover, the first stage assumptions should be based on past experimental measurements and field studies.

The case building: By defining thermal thermostats for the thermal zones and based on the primary properties of the building, the cooling and heating sensible energy was calculated monthly. It was observed that the highest energy demand is for the coldest month, and the lowest is in the two transition periods (after winter and after summer). Additionally, as the climate is cooling-dominated, the primary energy demand is heating (Figure 6).

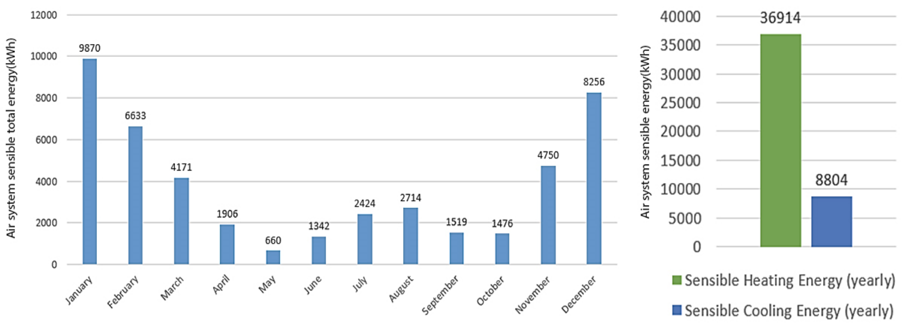

Figure 6. From right to left: Total monthly air system sensible energy, Total heating and cooling sensible energy

Therefore, according to the graphs and climate related properties which are discussed before, the main approach of the scenarios should be based on heat loss reduction during cold months. However, some passive actions, such as using shadings in hot months can reduce sensible cooling energy which is not enough.

Due to low solar heat gain, the highest sensible energy was for the stairs in the cold seasons and the western bedroom. In addition, the lowest sensible energy was for kitchen cooling due to lateral adjacency to the ground, vertical adjacency to the facility part, and limited solar heat gain in the west. Another reason for the high heating demand in the stair zone is its height and large window in the north. In cold climate regions, using large windows is not recommended because they could cause a lot of heat loss. Furthermore, in terms of visual comfort, large, unprotected windows increase the chance of glare in residential buildings. During summer, the southeast bedroom will consume the most cooling energy (Figure 7).

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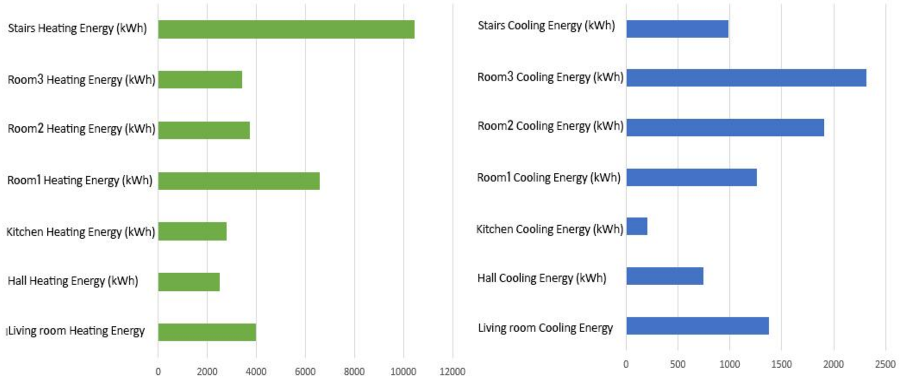
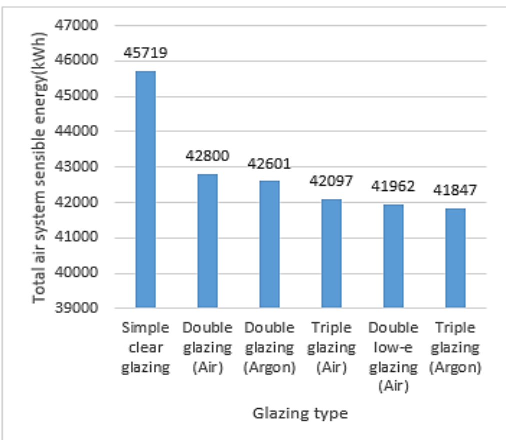


Figure 7. From right to left: Heating sensible energy (kWh) and cooling sensible energy (kWh) for each zone

Window: Compared to single-glazed windows, double and triple-glazed windows incorporate multiple layers of glass surrounded by insulating air pockets or gas pockets. This reduces heat transfer and improves energy efficiency. The temperature difference between the interior and exterior surfaces of single-glazed windows is also more likely to cause condensation. This may lead to issues like mold and mildew, affecting indoor air quality and potentially causing damage to the window frame. Regarding wooden frames, wood itself has some insulating properties, but it is not as effective as other materials used in modern window frames, such as vinyl, fiberglass, or aluminum with thermal breaks. Accordingly, the windows change from traditional single-pane (6mm, Solar transmittance 0.77) with wooden frames to double-pane (6mm and 4mm, Solar transmittance 0.77 and 0.84) with PVC frames and an air-filled cavity. The results show a 6.4% reduction in cooling and heating energy demand. The highest solar heat gain is from the greenhouse, which is desirable in the cold periods and will lead to higher energy consumption on hot days. Following that, the impact of four glazing types on energy demand was investigated. The results show that Argon-filled triple glazing has the best performance, and then double glazing with low emission (Low-E solar transmittance 0.6) coating on the inside reduces the energy by 8.4% and 8.2%, respectively. Also, Low-E double glazing has better performance than triple glazing (Figure 8).



Window type	Elements from outside to inside
Simple glazing + wooden frame	Clear 6mm
Double glazing + PVC frame (Air)	Clear 6mm
	Air 13mm
	Clear 4mm
Double glazing + PVC frame (Argon)	Clear 6mm
	Argon 6mm
	Clear 4mm
Triple glazing + PVC frame (Air)	Clear 6mm
	Air 13mm
	Clear 4mm
	Air 6mm
	Clear 4mm
Double low-e glazing + PVC frame (Air)	Clear 6mm
	Air 13mm
	Low-e clear 4mm
Triple glazing + PVC frame (Argon)	Clear 6mm
	Argon 13mm
	Clear 4mm
	Argon 6mm
	Clear 4mm

Figure 8. Total air system sensible energy for various window types

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Shading: Shading evaluations were conducted using 40 cm horizontal shadings on the south and west and 30 cm vertical shadings on the west. The vertical shading blocks direct sunlight when the sun is lower. According to the results, the fixed shadings did not cause a noticeable change in annual cooling and heating sensible energy in this climate since they prevented solar gains on cold days and reduced cooling on hot days. In addition, if the shadings are controllable or have a greater depth, less cooling energy will be consumed in hot months, and by closing the shading in cold months, more energy will be saved (Figure 9).

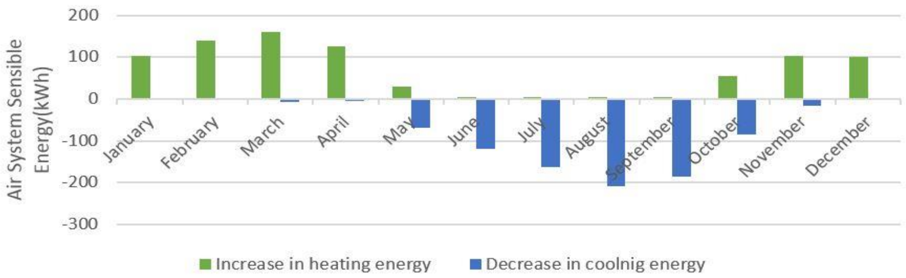

Figure 9. The difference between the heating and cooling sensible energy of the building with fixed shadings compared to the case without shadings

Insulation: Insulation materials reduce the rate of heat transfer through the building envelope. In addition to keeping the indoor temperature stable, insulated walls, roofs, and floors minimize the need for mechanical systems to compensate for heat loss or gain. This, in turn, leads to lower energy consumption and reduced utility bills. On a larger scale, it can reduce environmental effects and fuel poverty. In this regard, five centimeters of fiberglass insulation with 0.04 (W/mk) thermal conductivity was added to the floor and roof construction of the building. Thermal conductivity is a measure of how well a material allows heat to pass through it when there is a temperature difference across the material and it can be affected by various factors (Hung Anh & Pásztory, 2021). The added layer reduced the building's cooling and heating energy demand by 20.7%. A similar thickness of insulation was added to the structure of the walls and caused a 42.5% energy reduction compared to the base case. As a result, wall insulation alone reduced sensible energy by 21.8%. Finally, the insulation thickness within the floor, ceiling, and walls increased to 10 cm and 48.7% compared to the uninsulated state and 10.8% compared to the 5 cm insulation state energy reduction was observed (Figure 10).

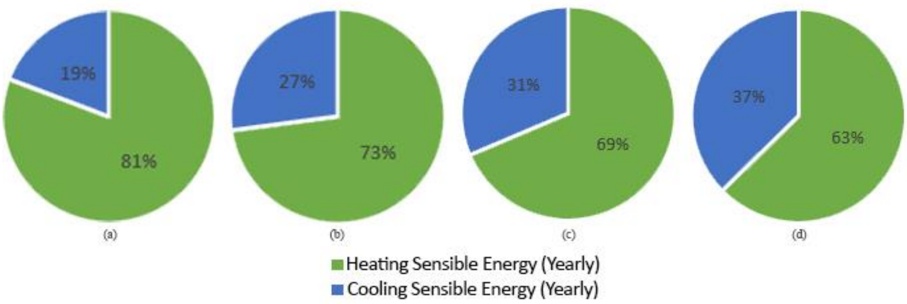

Figure 10. The contribution of cooling and heating sensible energy (a)without insulation (b) with 5cm roof and floor insulation (c) with 5cm wall, roof and floor insulation (d) with 10 cm wall, roof and floor insulation

DOI: 10.15320/ICONARP.2024.282

According to the results, building fabric insulation has a great impact on building energy demand compared to other scenarios, and the main impact of insulation is on the heating load of the building. Therefore, it can be considered as the answer to the research question and can be investigated in more detail to achieve higher energy efficiency.

Natural ventilation: Natural ventilation as a passive solution reduces the reliance on mechanical ventilation systems, leading to lower energy consumption. It also helps in removing indoor pollutants and ensuring a fresh supply of outdoor air. However, the best option is that make it as a part of a hybrid system that combines both passive and mechanical methods for optimal performance. In this regard, the greenhouse schedule was changed, so during the cold days, the openings between the living room and greenhouse would be open, while at night or on hot days, they would be closed. Also, airflow between the greenhouse, the living room, and the stairs was set, which increased the total heating energy and decreased the total cooling energy, which resulted in a 3.3% reduction in total sensible energy. Covering the upper surface of the greenhouse on hot days is also one of the strategies that causes a 14.5% reduction in cooling energy (Figure 11).

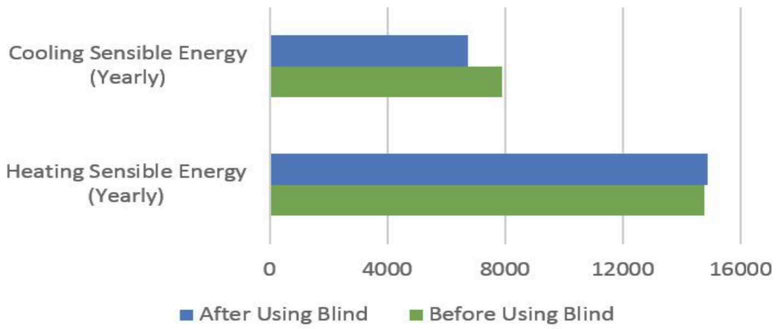

Figure 11. The effect of using blinds on top of the greenhouse

Greenhouses also can play a multi-functional role in buildings as a passive element. For example, to prevent overheating on hot days by increasing the greenhouse infiltration rate, it is assumed that the greenhouse has a flexible structure that folds on hot days and extends on cold days. Thus, it reduces cooling sensible energy by 1.6%.

Orientation: Another influential factor associated with energy demand is the proper orientation of the building according to climate, layout, and function. If the building is not properly oriented to take advantage of natural ventilation and solar gain, there may be a higher reliance on mechanical heating, ventilation, and air conditioning (HVAC) systems. This can increase operational costs and environmental impact. A comparison of the four main orientations found that the highest energy demand is in the western case, and the lowest cooling sensible energy is in the northern case. Simulation results indicate that an optimal layout and orientation can reduce energy demand by 12.3% (Figure 12).

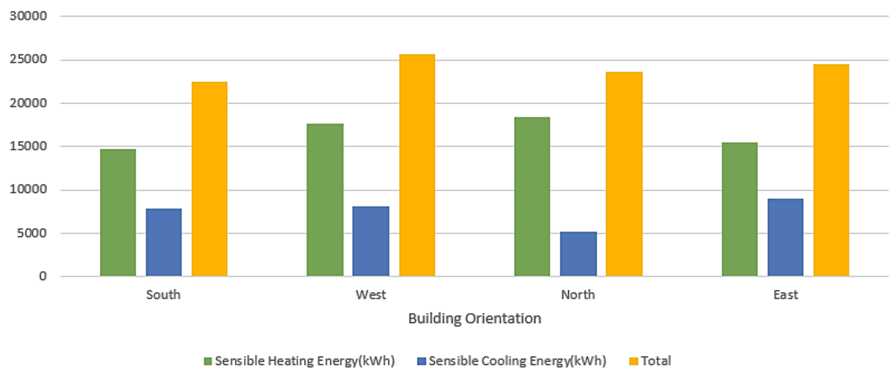

Figure 12. The effect of building orientation on sensible energy

After applying all the changes, the total cooling and heating energy decreased by 50.8% compared to the base case. Considering that heating energy decreased by 22217 kWh, the focus of building optimization should be on heating energy efficiency and improving the results by considering the optimum options in the early design stages (Figure 13).

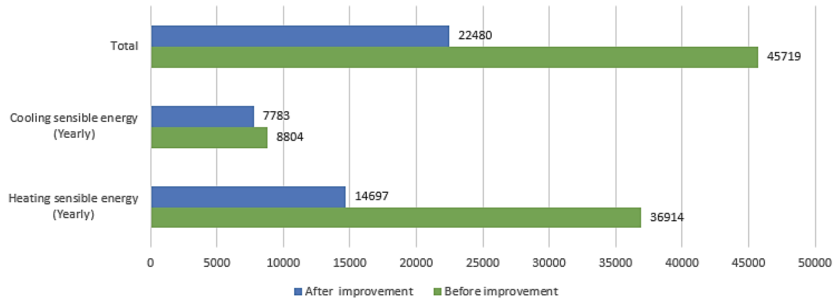

Figure 13. Heating and cooling sensible energy alteration

According to the findings, there is no doubt that passive approaches are a practical way of controlling energy demand in cold climate residential buildings. It can lead to various positive outcomes, such as less environmental impacts, lower utility costs, stable indoor temperature, and more energy security. However, if there is no possibility of using all passive design methods, they can be prioritize based on the energy outputs. For example, using insulation in building fabric would be the most practical way of energy demand reduction in similar buildings.

The results are based on modeling in EnergyPlus. The outputs of this software have relative errors, but it has a lower error rate than other energy analysis software and has been validated many times (Queiroz et al., 2020). On the other hand, in this study, a comparative analysis of passive systems in a case building is considered, and the difference is compared to the baseline model.

DISCUSSION

According to the results of the previous steps, insulation has the greatest impact on reducing sensible energy for buildings in cold climates. The following three questions can be discussed when installing thermal insulation inside building envelopes: (1) What is the most effective insulation material for cold climates? (2) What is the optimum

DOI: 10.15320/ICONARP.2024.282

insulation thickness for the building's envelope? (3) Where is the most effective placement of insulation inside the building's envelope?

According to the research method, further analysis is also conducted step by step to determine the optimal passive option. Equations of thermal resistance and thermal conductivity are used for detailed analysis to answer these questions.

Material: Based on factors such as price, transportation, and implementation cost, glass fiber, expanded polystyrene, mineral wool, and rigid polyurethane are the most common insulation materials in Iran. Different insulation materials with the same thickness of 5 cm were applied in the outer layer of the walls, as shown in Table 3.

Table 3. Comparison of different insulation materials

		Elements From Outside to Inside	Thickness (m)	Thermal Conductivity (W/m-K)	Thermal Resistance (m2-K/W)	U-value (W/m2-K)
Exterior Wall Cross Section		outside air film			0.04	
		Cement board	0.03	0.58	0.052	
		Cement plaster	-	-	0.026	
	Insulation Layer Options	a) Expanded Polystyrene	0.05	0.029	1.724	0.47
		b) Glass Fiber	0.05	0.04	1.25	0.605
		c) Mineral Wool	0.05	0.035	1.429	0.546
		d) Rigid Polyurethane	0.05	0.023	2.174	0.388
		Concrete 1600 (kg/m3)	0.2	2	0.1	
		Gypsum plaster	-	-	0.066	
		Inside air film			0.12	

The U-value of the entire wall will be 2.477 (W/m2-K), which, by using insulation and according to the results of Table 4, the best performance in reducing heat loss belongs to rigid polyurethane, which is 0.388 (W/m2-K).

Thickness: Insulation thicknesses from one to ten centimeters are checked. Findings show that, as insulation thickness increases, the rate of effectiveness decreases. The process aims to achieve the optimal thickness, so unconventional thicknesses are avoided (Table 4).

When the difference between a case thermal improvement and the thermal improvement in the previous case is not remarkable, it will be selected as the optimal thickness.

The equation is: $D=\frac{B-A}{B}$

Where (D) is the percentage of improvement, (A) is the U-value of the wall with the previous thickness, and (B) is the U-value of the wall with the chosen insulation thickness. Based on the results, a thickness of 7 cm of rigid polyurethane is recommended.

Table 4. Comparison of different thicknesses of polyurethane insulation

	Elements from outside to inside	Thickness (m)	Thermal conductivity (W/m-K)	Thermal Resistance (m2-K/W)	U-value (W/m2-K)
Exterior Wall Cross Section	outside air film			0.04	
	Cement board	0.03	0.58	0.052	
	Cement plaster	-	-	0.026	
	Rigid Polyurethane	0.1	0.023	4.348	0.21
		0.09	0.023	3.913	0.232
		0.08	0.023	3.478	0.258
		0.07	0.023	3.043	0.29
		0.06	0.023	2.609	0.332
		0.05	0.023	2.174	0.388
		0.04	0.023	1.739	0.467
		0.03	0.023	1.304	0.585
		0.02	0.023	0.870	0.785
		0.01	0.23	0.0435	1.193
	Concrete 1600 (kg/m3)	0.2	2	0.1	
	Gypsum plaster	-	-	0.066	
	Inside air film			0.12	

Placement: Another step in optimizing insulation is to indicate the location of the insulation inside the wall, which results in the maximum reduction in thermal loads. Thermal insulation can be applied to the inner side, outer side, and middle of the wall. As shown in Table 5, installing insulation in the outer part results in less total heating and cooling energy compared to other options. Therefore, based on previous findings about insulation, including material and thickness the best option is 7 cm rigid polyurethane insulation in the outer part of the wall (Table 5).

Table 5. Comparison of polyurethane insulation location

Insolation location	Air System Sensible Heating Energy [kWh]	Air System Sensible Cooling Energy [kWh]	Total Air System Sensible Energy [kWh]
Status 1: Outer layer	15991	5448	21439
Status 2: middle layer	16024	5462	21486
Status 3: Inner layer	16166	5645	21811

It is important to note that the location of different insulations changes in hot and cold climates. Also, the efficiency of different types of insulation varies depending on the material and location. In conclusion, although fabric insulation was selected as the most effective passive scenario, it is still necessary to analyze insulation in detail to find the optimal state of the system based on the research questions. Further simulation outputs showed that using rigid polyurethane with 7cm thickness in the outer part of the walls is recommended based on the evaluation of different thermal insulation scenarios. However, the cost of retrofitting or construction of passive buildings are not considered in this research that can have a huge effect on user preferences. As a result, a pay back period analysis is recommended during the process of passive design. There are also some new insulation materials and technologies which are not

DOI: 10.15320/ICONARP.2024.282

available in some countries but can be used to achieve better energy efficiency in buildings.

CONCLUSION

Nowadays, much energy is consumed to provide comfort in buildings. Assessing energy demand and providing appropriate strategies to increase energy savings is necessary. A useful method of determining energy demand is using simulation software, such as EnergyPlus. In this study, a simple building model is selected, and building air loads in different passive design conditions in a cold climate are simulated and compared.

Different passive methods are investigated, including natural ventilation, orientation, shading, window type and fabric insulation. Each stage has a range of reductions on energy load, but some have more impact in the selected climate. Results in response to the first-mentioned research question show that heat loss through the building envelope is a major energy drain, and installing thermal insulation in the envelope layers plays the most important role in preventing it. The findings are like the conclusions of Asghari et al. (2018), who, by comparing two passive strategies (shading and insulation), concluded that thermal insulation is more efficient than shadings. Regardless of increasing the shading depth, there will still be no significant reduction in energy demand.

Following the first part, by selecting thermal insulation as the most effective option, it is still necessary to investigate this factor in more detail. It can result in less energy demand and more user comfort. Therefore, in response to the second-mentioned research question, according to the study of different insulation materials, thicknesses, and location, the optimal condition is using rigid polyurethane insulation with 7 cm thickness in the outer layers of the building envelope. After comparing different insulations with the same thickness, Kazemi Pouran Badr et al. (2020) concluded that polyurethane insulation has better efficiency than other insulation materials. Although, these results differ from a published study by Eskandari et al. (2017). They claim that most insulation types, except Polyurethane and fiberglass used in roof layers, are effective in cold climates. Also, the best insulation is expanded polystyrene.

The results suggest that based on the climate, the envelope material and thickness, and insulation material, insulation thickness should be determined first, then its location inside the envelope should be evaluated to achieve the best result. Using proper passive design method can lead to less energy consumption in the building sector and consequently less following negative impacts, such as GHG emissions, less user comfort, and high energy bills. It should be noted that the present study was conducted on permanently used buildings. In buildings frequently used (such as office buildings), estimating energy demand based on detailed schedules is necessary to decide on proper insulation methods. Also, further work may consider other climates and simple case study model, as this study was conducted in a cold climate. It may result in different passive methods and different technologies and materials.

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Resume

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