Climatic Evaluation of Projects for Improvement of Rural Housing (Case study: Mountainous Areas of Tehran Province)

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Abstract
Indigenous architecture is derived from nature, climate and the environment, and due to limited access to modern fossil energy sources, has tried to have the least degree of dependence on them. Imitating the indigenous architecture of a region is the first and most sustainable step in designing climate-friendly architecture. The Housing Foundation of the Islamic Revolution, as the main organization of housing in rural areas of Iran, has conducted extensive studies to identify and evaluate the features of indigenous architecture in rural housing and has presented a plan to improve rural housing in some climatic regions. The purpose of this article is to evaluate the projects of improving rural houses in mountainous areas of Tehran regarding energy consumption and, if necessary, provide corrective solutions to improve their thermal performance. For this purpose, it is necessary to first evaluate the energy consumption of rural housing in projects prepared by the Housing Foundation and compare them with the standards of energy consumption in Iran. If the level of energy consumption is higher than the standard, it is necessary to use corrective solutions. Corrective solutions are derived from the physical characteristics of the optimal model. Physical characteristics of the optimal pattern represents the optimal state of physical characteristics of a building such as length-width ratio, building orientation, number of floors and building density, surface-to-volume ratio, wall-to-window ratio, the relationship of optimal pattern with adjacent buildings, number and direction of exterior walls in terms of fresh air, the presence of semi-open spaces (porches), the protrusion of the roof, the canopies and the color of the exterior walls in a specific climate that can be achieved with the help of rules, standards and energy simulations. The final goal of this article is to evaluate and modify the physical features of the projects for improvement of rural housing in the mountainous areas of Tehran province. This is achieved by adapting them to the optimal state of the physical features of the building in this climate. The method of this research is descriptive which has been done using simulation tools and Energy Plus 9.3 software. The results indicate that the implementation of remedial strategies will save energy by 29% in these projects.

Keywords: Rural Housing Plan, Architectural Design, Building Energy, Physical Properties, Energy Plus Software.

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Introduction

The influence of climate on housing and human comfort is an issue with a long history that dates back to several centuries before Christ (Octay, 2002: 1003-1012), and people have always tried to make the architectural design in harmony with the characteristics and climatic factors of the region to have a comprehensive plan (Chairuniza et al., 2020: 2056-2059; Malek Hosseini, 2010). Indigenous architecture of Iran indicates that attention to natural energy resources has existed for a long time and their use has led to savings in fuel consumption and more importantly to improve the quality of comfort and health of residential environments and environmental health. The first step in this direction is the coordination of residential environment with climatic conditions (Kasmaei, 1989). In general, the physical characteristics of the building have a direct impact on energy consumption and it is necessary to be in maximum adaptation to the climate of the region (Mirzaei et al., 2019). Attention to physical characteristics must be determined from the very first stages of design. Some of these features are flexible and can be changed during the operation of the building, while others are determined at the beginning of the design process and cannot be easily changed after construction because it is associated with high costs (Hayter et.al, 2001).

This article is concerned with cold climate, which covers a large part of Iran. The Alborz and Zagros Mountain Ranges, as well as the mountains that exist individually in central and eastern Iran, are considered cold regions of the country (Majedi, 1992). Due to the favorable living conditions, many villages have been formed in the mountainous areas of Alborz, including the mountainous villages in the northeast of Tehran province.

The Housing Foundation of the Islamic Revolution in 2007 in a study entitled "Special Plan to Improve Rural Housing in Tehran Province" has provided models for rural housing in the mountainous areas of Tehran Province. The proposed models are based on social, cultural and economic studies of rural housing in the region. The present article seeks to answer these questions: To what extent have the proposed models paid attention to the thermal performance of the building? How compatible are the physical features considered in the proposed models with the mountainous climate of the region? And what should be the optimal state of physical characteristics of rural housing in the mountainous areas of Tehran province so that the building has good thermal performance throughout the year?

In order to answer the questions, the present article intends to examine the proposed models in terms of energy performance and, if necessary, propose the necessary modifications in them. In order to achieve this goal, it is first necessary to identify the optimal state of the physical characteristics of the building in the desired climate. Then the proposed models are evaluated in terms of energy consumption and in case of excessive consumption of energy standard, corrective strategies should be used to improve energy consumption. Thus, by recognizing the optimal state of the physical characteristics of rural housing in the desired climate, it is possible to evaluate rural housing improvement projects in terms of energy consumption which can be considered in addition to social and economic characteristics in terms of energy and environmental function.

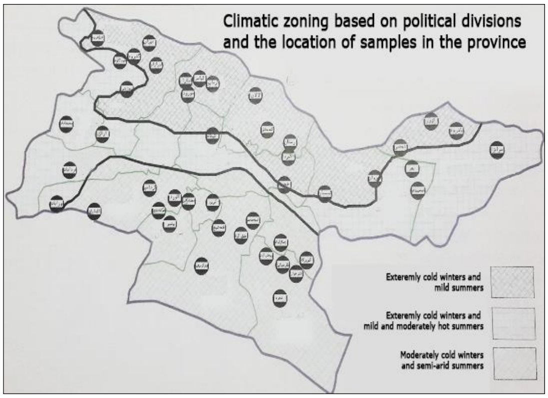
Literature Review

In general, many studies have been conducted on the use of climatic elements in architectural design and building energy, and many recommendations have been made on the use of local climatic conditions to improve climatic designs and energy simulations (Timothy et al., 2016: 71-74; Hui and Chung, 1997: 1-9). Climatic studies can be pursued in various fields and scales. For instance, we can refer to the climatic zoning map of Iran in relation to housing and residential environments throughout the country, which is on a scale of one to four million (Kasmaei, 1993). Also, using the meteorological data of 48 synoptic stations, Kaviani has studied and prepared a map of the human climate of Iran based on the Terjang index (Kaviani, 1993: 45-262). However, in the micro-scale, a comprehensive study on the adaptation of buildings to the climate of the region has not been done and it is necessary to pay more attention to this matter in future designs. The adaptation of the building to the climate can be in terms of the space inside the body of the building such as the type of arrangement of interior spaces (Tiantian et al., 2020) and the external dimensions of the body such as the total volume of the building (Ying and Li, 2020; D'Amico & Francesco, 2019; Khamma & Boubekri, 2017; Wei et al., 2016; Sharizatul et al., 2016; Konis et al., 2016; Delmastro, et al., 2015: 91-94; Kocagil and Oral, 2015; Naboni et al., 2015) , building orientation (Chi et al., 2020; Ram Khamma and Boubekri, 2017; Delgarm et al., 2016; Hemsath and Bandhosseini, 2015), number of floors and building density (Geekiyanage and Ramachandra, 2018; Premrov et al., 2017), wall-to-wall ratio (Geekiyanage and Ramachandra, 2018; Premrov et al., 2017; Wei Tian et al., 2016), building dimensions (Premrov et al., 2017; Hemsath and Bandhosseini, 2015) and building exterior (D'Amico & Francesco, 2019). Many studies on construction have been conducted in Iranian villages by the Housing Foundation of the Islamic Revolution, with scant attention to environmental issues. Since sustainable architecture depends on addressing the three principles of economic, social and environmental sustainability; therefore, it is necessary to conduct more detailed and comprehensive studies on the adaptation of architecture and climate of the region. The Housing Foundation of the Islamic Revolution in a study entitled "Typology of Rural Housing in Tehran province" (2008) has studied rural housing in Tehran province in plains, foothills and mountains. In mountainous climate, 20 villages and 120 rural houses were analyzed in terms of typology, patterns and livelihood. In another study entitled "Rules, Criteria and Guidelines for Architecture and Structure of Renovation and Reconstruction Projects of Rural Housing in Tehran Province" (2011), the foundation has also designated the rules and criteria for designing rural housing in Tehran province to guide the design of architects in villages in this province. In this study it is mentioned that there are three climatic regions: plain, foothill and mountainous. In another step, the Housing Foundation has analyzed the physical characteristics of rural buildings in a study entitled "Report on the Survey of Rural Housing Characteristics in 2013" in the form of statistical studies. Another action of the Housing Foundation was to provide design models for rural housing, which has been prepared in the form of a study entitled "Special Plan for Rural Housing Improvement in Tehran Province" (2007) and part of it is allocated to the mountainous areas of Tehran Province. The present paper intends to evaluate the models proposed in this study in terms of energy performance and to apply corrective strategies if necessary. Energy consumption of rural housing plan models should be evaluated in order to achieve this goal. After that, we should compare the models with the standard energy consumption in the housing sector and if the energy consumption is excessive, it is necessary to use corrective solutions to improve the thermal performance of the building. In this way, it is possible to achieve models of rural housing projects that, in addition to social and economic issues, have also paid comprehensive and in-depth attention to environmental issues. Due to the high impact of climate in the architectural design, it is necessary to carefully study the climatic and geographical features of the research area.

Case Study

The study area is the northern part of Tehran province (Figure 1), which is located on the southern slopes of the Central Alborz Mountains and is considered a mountainous area (Islamic Revolution Housing Foundation, 2008, p. 28). The villages of Damavand, Firoozkooh, Shemiranat, Lavasan, Karaj, Savojbolagh, Taleghan and Tehran are located in this area.

The climate of these villages is in the Ds group based on the Köppen climate classification. To determine the comfort temperature as well as the temperature conditions of the months of the year, it is possible to use previous research conducted by experts in this field in relation to the thermal comfort of Tehran. Heidari (2008) has studied Tehran's climate based on the Ashrae & Point Scale, and with the assumption that very cold conditions refer to conditions where the average monthly temperature is less than 15 degrees. Table 1 shows the results of this study.



F1. Area of the study area (Islamic Revolution Housing Foundation, 2008, p. 51)

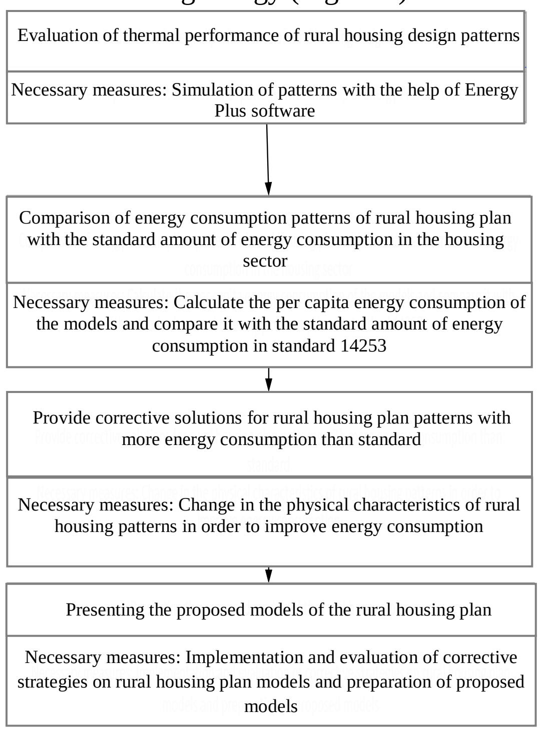
Slightly cold		**Neutral**		**Slightly hot**		**Hot**	
3 Apr.	20 Apr.	20 Apr.	20 Jun.	20 Jun.	5 Jul.	5 Jul.	20 Jul.
Very hot		**Hot**		**Slightly hot**		**Neutral**	
20 Jul.	20 Aug.	20 Aug.	5 Sep.	5 Sep.	20 Sep.	20 Sep.	21 Oct.
Slightly cold		**Cold**		**Very cold**		**Cold**	
22 Oct.	5 Dec.	5 Dec.	4 Jan.	4 Jan.	19 Feb.	19 Feb.	3 Apr.

T1. Distribution of Tehran Climatic Conditions based on Ashrae Classification (Heidari, 2008: 10)

Thus, Tehran has 62 hot or very hot days, has balanced conditions in half of the year and 122 cold or very cold days. In this research, based on studies and field work results, the comfort and neutral temperature range of Tehran has been determined for cold and hot seasons. Neutral temperature in the cold season is 22.5 and in the hot season is 27.5 degrees and the temperature of thermal comfort for the people of Tehran is at ± 4 degrees relative to the neutral temperature (Heidari, 1387: 11-9).

Research Method

Addressing energy issues should be considered from the earliest stages of building design. If this principle is not observed from the beginning of the design, it can be done at any stage of the design, but one should no longer expect 100% thermal efficiency from the building. As mentioned earlier, sustainable housing is one that is considered from social, economic and environmental dimensions. In order to have sustainable patterns of rural housing project in Tehran province, it is necessary to first examine the type of thermal performance of the building with the help of energy simulation and compare the amount of energy consumption with its standard state. If the energy consumption of the building is high, it is necessary to modify the architectural design of the proposed patterns and reduce their energy consumption by using climatic solutions of architectural design. In this regard, the official rules, standards and instructions of Iran, such as the nineteenth and thirteenth articles of the National Building Regulations, and the National Standard of Iran 14253, have been used in the field of building energy (Figure 2).



F2. Research process and measures

Due to its location in the cold climate, the present project area requires maximum use of solar radiation for lighting and heating of indoor spaces, and natural ventilation is limited to providing fresh air only when necessary. Much of the research evaluation has been done by simulation with Energy Plus Software version 9.3.

Discussion

Based on the study of "Special Plan for Improvement of Rural Housing in Tehran Province", 23 models of architectural plans for rural housing in Tehran Province in mountainous areas have been proposed. Table 2 presents the outline of the 23 mentioned schemes and the per capita energy consumption of each of them obtained by energy simulation. It should be noted that in all models, the thickness of the outer shell is equal to 20 cm, which is made of brick and has no thermal insulation. The internal useful height is 2.70 m., and the roofs are sloping. The height of the window floor for the kitchen space is 90 cm, rooms are equal to 60 cm and toilets are equal to 160 cm. In the current situation, most doors also have a glass surface so that up to 70 cm in height is metal and the rest of the height is made of glass. Also, the windows are considered as single wall, plain glass with a thickness of 6 mm, the material of the windows frame is made of metal (without internal division), the roof heat transfer coefficient is 2.5 W/m^2.K and the outer shell heat transfer coefficient is 1.77 W/m^2.K. These patterns fall into two categories in terms of the number of walls associated with the outside air. The first group are related to the outside air in four sides and most of the patterns are in this category. The second category includes buildings that are connected to the outside air in two sides, and models 3 and 23 are in this category. It should be noted that Energy Plus software has been used to determine the per capita amount of energy consumed by the models.

Pattern	Description	Energy per capita (kWh/m^2)	Pattern	Description	Energy per capita (kWh/m^2)
	1. Living space in the east and livestock space in the south	151.26		13. Living space in the east and livestock space in the south	172.18
	2. Living space in the center and the livestock space in the north of the earth	162.28		14. Living space in the east and livestock space in the south	185.83
	3. Living space in the north and livestock space in the south	132.32		15. Living space in the west and livestock in the south	153.29
	4. Living space in the west and livestock in the north	192.97		16. Living space in the west and livestock in the south	154.07
	5. Living space in the center and livestock spaces in the north	164.28		17. Living space in the west and livestock in the north	166.15
	6. Living space in the center and livestock space in the south	156.74		18. Living space in the west and livestock in the south	165.97
	7. Living space in the east and livestock space in the south	144.79		19. Living space in the west and livestock in the south	170.39
	8. Living space in the east and livestock space in the south	141.63		20. Living space in the west and livestock in the south	180.88
	9. Living space in the center and livestock space in the south	178.57		21. Living space in the West	144.45
	10. Living space in the east and livestock space in the south	149.96		22. Living space in the West	160.32
	11. Living space in the east and livestock space in the south	137.69		23. Living space in the center of the earth	150.55
	12. Living space in the center and livestock in the north	162.77			

T2. Physical and Per capita Characteristics of Energy Consumption in Rural Housing Plan Models (Islamic Revolution Housing Foundation, 2007)

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Evaluation of energy consumption of rural housing projects in mountainous areas of Tehran province

In National Standard No. 14253 of Iran, the energy consumption index of the ideal residential building in cold climate is specified as 111 W/m2.K. Meanwhile, according to Table 2 per capita energy consumption, the patterns of the rural housing plan are between 132.32 W/m^2.K and 192.97 W/m^2.K. Therefore, it is necessary to modify the physical properties of the building as much as possible to bring the energy consumption of the models closer to the standard value. For this purpose, it is necessary to study the optimal state of housing characteristics in the cold climate of the region and use them as corrective solutions for climate architecture design in modifying the architectural design of rural housing improvement plans in the mountainous areas of Tehran province. In the following, an attempt is made to present the optimal state of all physical features of the building in the cold climate of the region in the form of an optimal model.

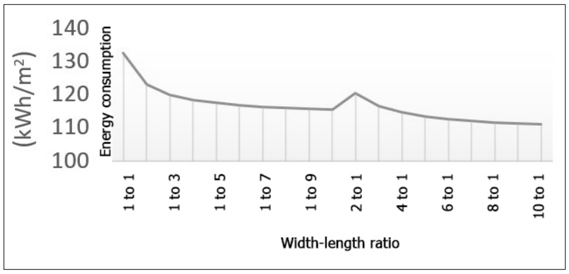
Optimal pattern

Obtaining the physical characteristics of the optimal form for the desired climate in the early stages of design will be very beneficial in terms of energy savings, while not costly (D'Amico & Francesco, 2019). In order to obtain the optimal state of the desired physical characteristics, a hypothetical sun-facing building in the Northern Hemisphere with dimensions of 3 × 10 × 20 m was modeled in Energy Plus software version 9.3. The proportions of the hypothetical model are derived from the predominant proportions in the existing buildings of rural housing in the region. The walls are made of clay and brick with a thickness of 35 cm with a heat transfer coefficient of 1.77 W/m^2.K and without insulation and the ceilings are made of beams with a thickness of 30 cm with a heat transfer coefficient of 2.5 W/m^2.K and without insulation. The type of windows is in the form of simple single-walled glass with a thickness of 6 mm and the material of the frame around the windows is metal and the windows do not have an internal partition.

Achieving the optimal model requires a multi-step simulation process. First, according to the climate of the region, the best dimensions of the building and then the best orientation are examined, and in the next stage, the building is examined in terms of the number of floors and wall-to-window ratio. The results of the simulation considering the above conditions are presented below.

Optimal pattern dimensions

Figure 3 shows that increasing the length-to-width ratio in east-west buildings will increase the amount of sunlight received. Another important point in determining the dimensions of the building is to consider the prevailing wind direction of the area. Research shows that the prevailing wind in 50% of the villages in the study area is north-south, 20% is east-west, 20% is northeast-southwest and 10% is northwest-southeast. Due to the cold climate of the region and in order to maximize the benefit of sunlight and not receive cold wind in the region, in the first step of housing design, it is recommended that the building be stretched northeast-southwest to be safe from the cold wind in addition to receiving southern radiation. However, if there are design limitations, it is suggested that the building has the least elongation in the east-west or southeast-northwest direction.



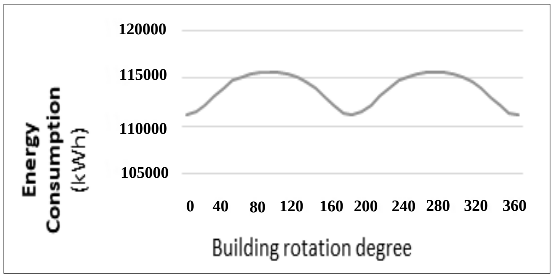
F3. Relation of building length to width ratio and energy consumption with each other

As mentioned, the direction of the building is related to two important factors, one is sunlight and the other is the prevailing wind in the area. Figure 4 shows that the best thermal performance of a building is when the larger side of the building faces south. However, the prevailing wind of the area has north-south direction, which is tried to be avoided due to the cold. According to the previous explanations, the best orientation of the building is northeast-southwest.

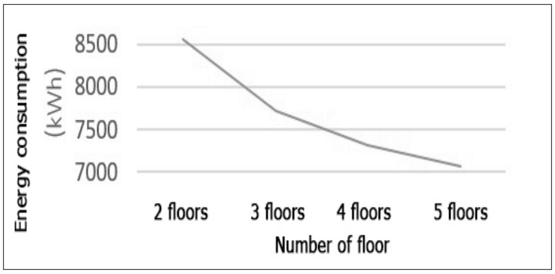
The south direction is considered as the origin of rotation in a clockwise direction.

umber of optimized floors

In cold regions, by repeating the floors in height and increasing the number of floors, the density increases and the surface-to-volume ratio decreases, which has a positive effect in terms of energy consumption in the building (Figure 5).



F4. The relationship between building direction and energy consumption



F5. Relationship between the number of floors of a building and energy consumption

all-to-window ratio in optimal pattern

Wall-to-window ratio is determined by considering the two criteria of "peak sun hours" and "useful daylight illuminance". Among these two criteria, the parameter of "peak sun hours", which is directly related to the amount of sunlight, is more important because in cold climates, rural housing requires more than natural light to provide indoor thermal comfort. This can be seen in the type of construction of indigenous housing in the region. Therefore, the first principle in determining the dimensions of the windows is to provide internal thermal comfort for a longer period of time during the year. The next issue to be addressed is the issue of providing lighting for interior spaces. As mentioned earlier, the region in question has a cold six months and the temperature of thermal comfort in the cold season of this region is between 18.5 to 26.5 degrees Celsius. Also, this region has three warm months and the temperature of thermal comfort is between 23.5 to 31.5 degrees Celsius in the warm season (Heidari, 2008: 9). In the following, window-to-wall ratio of different facades of the building have been studied separately in the two cold and hot seasons. The results show that increasing the amount of WWR is directly related to the amount of thermal comfort in the building in the hot and cold seasons. For the north facade of the building, the best wall-to-window ratio in the hot season is 60%. However, in the cold season, the thermal performance of the building decreases by increasing the window-to-wall ratio (from ten to one hundred percent). Changing the WWR value from 10% to 60% makes the building less comfortable within 95 hours or 4 days. The number of cold days in this region is 122 days, of which 4 days are not significant. Therefore, WWR can be increased up to 60% on this front and the appropriate UDI can be used for a longer period of time. However, it should always be borne in mind that in the housing sector, the importance of lighting is less than thermal comfort.

On the east and west fronts, increasing the amount of WWR in the cold season leads to a decrease in thermal performance and in the warm season increases the thermal performance of the building. The simulation results show that by increasing the amount of WWR from 10% to 50% by 23 hours (equivalent to one day), the comfort range of the interior space decreases in the cold season. Meanwhile, the indoor space in the warm season spends more time in the comfort zone (41 hours more, approximately equivalent to two days). Due to the cold climate of the region, it is suggested that the amount of WWR on the eastern and western fronts be equal to 10%. If we want to use the UDI for a longer period of the year, we can eventually increase the amount of WWR by up to 50%. However, as mentioned earlier, in the housing sector, providing thermal comfort is preferable to providing lighting (Figure 6).

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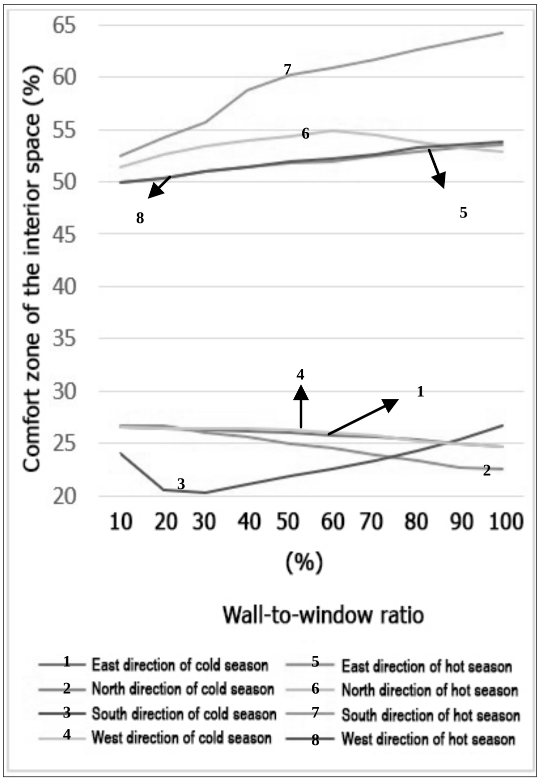
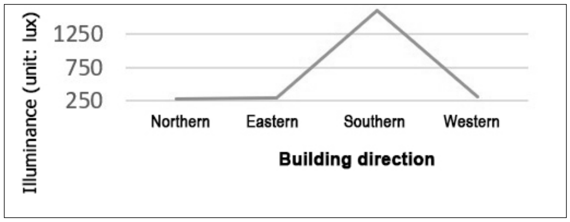


F6. Percentage of the interior comfort area in proportion to the percentage of wall-to-window ratio on the eastern, western, northern and southern fronts

As mentioned earlier, in order to determine WWR, in addition to receiving sunlight, the interior lighting must also be considered. Accordingly, 45 light sensors were placed on the floor of the optimal model building and the amount of annual light intensity of the indoor space was examined in the period of 7 am to sunset. According to Figure 7, the larger the dimensions of the shutters, the higher the amount of light received. According to the thirteenth article of the National Building Regulations, the average amount of lighting required for indoor spaces is equal to 200 lux (Article 13 of the National Building Regulations, 2016: 178). The simulation results show that the WWR value equal to 10% on the western, southern, eastern and northern fronts of the optimal model provides 200 lux of lighting required for indoor spaces. Therefore, the interior space will not face much limitation in terms of lighting.



F7. Interior illuminance for WWR with 10% on the west, south, east and north fronts of optimal pattern

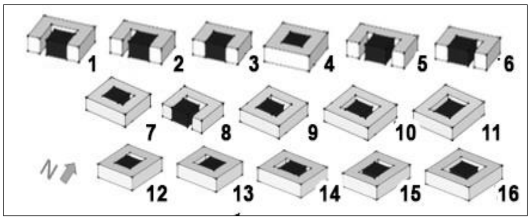
Considering the two parameters of thermal comfort and indoor lighting, it can be concluded that the best WWR in this climate in terms of thermal performance and lighting is as follows:

- The best wall-to-window ratio on the southern front is equal to 100%;
- In the northern front, the best wall-to-window ratio in terms of thermal performance is equal to 10%, and if you want to have more natural light indoors, it can be increased up to a maximum of 60%;
- On the eastern and western fronts, the best wall-to-window ratio in terms of heat is equal to 10% and to provide more natural light it can be increased up to 50%.

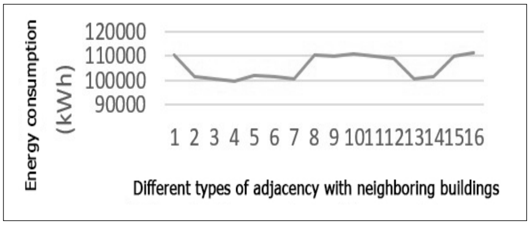
The type of optimal pattern relationship with adjacent buildings

Buildings in cold climates have a compact texture, and the proximity of buildings can have a positive effect on reducing energy consumption. Examining the issue of proximity to adjacent buildings in which directions can lead to optimal thermal performance of the building is a topic that is addressed in this section. Existing rural housing plans show that the yard is typically located on the south side of the building and allows the building to receive adequate south light, which is very necessary and useful in cold climates.

Figure 8 shows the type of relationship of the optimal model building with adjacent buildings. The best case among the various cases of connection of the optimal model building with adjacent buildings are those that have two characteristics: (a). existence of a yard on the south side; and (b). having low energy consumption. Accordingly, the fifth and second types have the best type of connection with adjacent buildings (Figure 9).



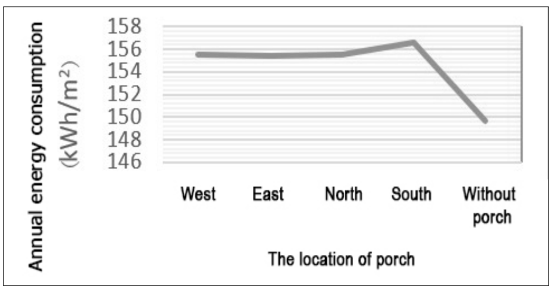
F8. Type of connection of the optimal model building with adjacent buildings



F9. The effect of the type of relationship between the optimal model and adjacent buildings with each other on the energy consumption of the optimal model

porch in the optimal pattern

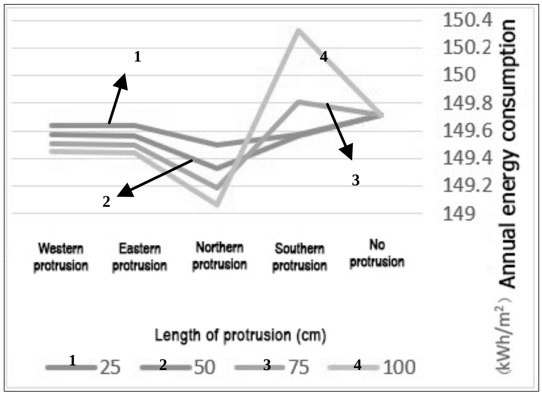
Nearly 80% of rural houses in this area have porches, which often cover an area equal to 5% of the building infrastructure. The effect of porch on the energy consumption of the building has been studied in 5 different cases. In the first case, the building is considered without any porch. In other cases, 5% of the building area is covered with a porch that is located on the southern, northern, eastern and western sides of the building. Due to the increase in surface to volume ratio and also the increase of shading on the walls of the building in general porches have a negative effect on energy consumption of the building and the best thermal performance may be reached without them.



F10. The effect of porch on the annual energy consumption of the building in the optimal model

Roof ledge protrusion in the optimal pattern

A study of 120 rural dwellings shows that due to the type of flat roof structure that is covered with beams, most of the buildings have a minimum protrusion of 20 cm at the edges of the roof and this amount reaches up to one meter in some cases. Figure 11 shows that the presence of a protrusion of 25 to 50 cm on the southern front is effective in a better thermal performance than when the building is without a protrusion or the protrusion is more than 50 cm. Increasing the protrusion between 0 and 100 cm on the north, east and west fronts reduces the energy consumption of the building.



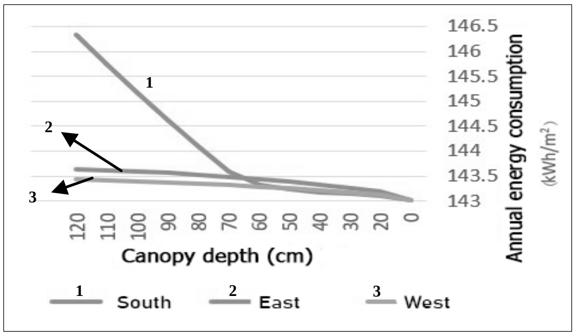
F11. The effect of roof ledge protrusion on energy consumption in the optimal pattern

Canopies in the optimal pattern

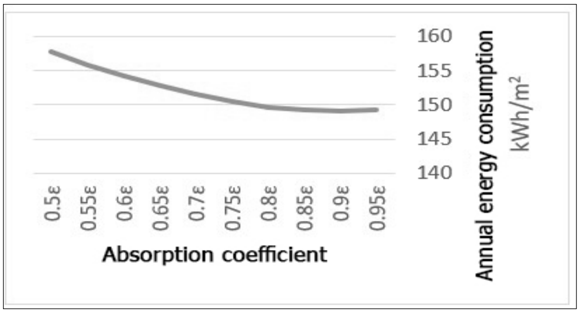
In this section, horizontal canopies are used for the southern windows and vertical canopies are used for the eastern and western windows, and the northern windows are without canopies. The results presented in Figure 12 indicate that increasing the depth of horizontal canopies on the southern side as well as the depth of vertical canopies on the eastern and western sides will increase the energy consumption of the building. Therefore, windows do not need canopies in this climatic zone.

The effect of color (light absorption coefficient) on the optimal pattern

Examination of 120 rural sample houses shows that the facade materials of 48% of the buildings are made of bricks and the other 46% are made of clay, stratification/clay and thatch. These materials are in the pale-yellow color spectrum and their absorption coefficient is between 0.5 to 0.7. In order to investigate the effect of light and dark colors on the energy consumption of the building, light absorption coefficient has been used with a range between 0.5 to 0.95. Figure 13 shows that the amount of light absorption coefficient is inversely related to annual energy consumption. Thus, the use of dark colors that have a higher absorption coefficient and thus less energy consumption for the building is suggested in this climatic region, and this is consistent with the cold climate of the region.



F12. The effect of canopy on the energy consumption of the optimal model



F13. Effect of color (light absorption coefficient) on the energy consumption of the optimal pattern

Modification and evaluation of the proposed models of rural housing projects in the mountainous areas of Tehran province

Matching the physical features of each of the rural architectural housing improvement projects with the physical features obtained for the optimal model can be used as corrective strategies to reduce the energy consumption of the building. Table 3 and Table 4 include some of the physical features of improvement plans as well as remedial solutions for these 23 rural housing improvement plans (Table 2).

Pattern No.	Direction		Proportion between the number of floors and the surface to volume ratio		Wall-to-window ratio (%)								Walls exposed to outside air	
					Existing				Modificatory					
	Existing	Modificatory	Existing	Modificatory	Northern	Southern	Eastern	Western	Northern	Southern	Eastern	Western	Existing	Modificatory
1	Northern-Southern	Eastern-Western	2 Fl (SVR=0.68)	3 Fl (SVR=0.63)	17	15	0	0	0	33	10	10	4 sides	3 sides
2	Eastern-Western	-	1 Fl (SVR=0.85)	2 Fl (SVR=0.68) 3 Fl (SVR=0.63)	24	16	0	0	0	33	10	10	4 sides	3 sides
3	Eastern-Western	-	1 Fl (SVR=0.95)	2 Fl (SVR=0.79) 3 Fl (SVR=0.73)	5	16	5	5	0	33	5	5	2 sides	2 sides
4	Northern-Southern	Eastern-Western	1 Fl (SVR=0.90)	2 Fl (SVR=0.73) 3 Fl (SVR=0.68)	16	15	13	15	6	33	18	10	4 sides	3 sides
5	Eastern-Western	-	1 Fl (SVR=0.88)	2 Fl (SVR=0.71) 3 Fl (SVR=0.66)	14	16	0	0	0	33	2	7	4 sides	3 sides
6	Eastern-Western	-	1 Fl (SVR=0.81)	2 Fl (SVR=0.64) 3 Fl (SVR=0.58)	14	16	0	9	0	33	5	20	4 sides	3 sides
7	Northern-Southern	Eastern-Western	2 Fl (SVR=0.62)	3 Fl (SVR=0.57)	18	14	0	3	0	33	7	5	4 sides	3 sides
8	Northern-Southern	Eastern-Western	2 Fl (SVR=0.64)	Fl (SVR=0.59)	16	19	10	0	0	33	8	7	4 sides	3 sides

T3. The first part of the proposed remedial solutions for 23 rural housing improvement projects in accordance with their existing plans

9	Eastern-Western	-	1 Fl (SVR=0.89)	2 Fl (SVR=0.79) 3 Fl (SVR=0.67)	18	10	0	9	0	33	7	9	4 sides	3 sides
10	Northern-Southern	Eastern-Western	2 Fl (SVR=0.62)	3 Fl (SVR=0.57)	18	18	7	8	0	33	7	7	4 sides	3 sides
11	Eastern-Western	-	2 Fl (SVR=0.68)	3 Fl (SVR=0.63)	16	14	0	0	0	33	8	6	4 sides	3 sides
12	Eastern-Western	-	1 Fl (SVR=0.88)	2 Fl (SVR=0.71) 3 Fl (SVR=0.66)	18	16	0	0	0	33	1.5	10	4 sides	3 sides
13	Northern-Southern	Eastern-Western	1 Fl (SVR=0.85)	2 Fl (SVR=0.68) 3 Fl (SVR=0.62)	22	30	15	0	0	33	10	10	4 sides	3 sides
14	Eastern-Western	-	1 Fl (SVR=1.05)	2 Fl (SVR=0.88) 3 Fl (SVR=0.83)	19	19	7	0	0	33	10	10	4 sides	3 sides
15	Eastern-Western	-	2 Fl (SVR=0.65)	3 Fl (SVR=0.59)	15	13	0	0	0	33	5	5	4 sides	3 sides
16	Eastern-Western	-	1 Fl (SVR=0.76)	2 Fl (SVR=0.59) 3 Fl (SVR=0.53)	11	16	0	0	0	33	5	5	4 sides	3 sides
17	Eastern-Western	-	1 Fl (SVR=0.84)	2 Fl (SVR=0.67) 3 Fl (SVR=0.62)	17	17	0	0	0	33	7	7	4 sides	3 sides
18	Eastern-Western	-	1 Fl (SVR=0.83)	2 Fl (SVR=0.66) 3 Fl (SVR=0.60)	15	15	0	0	0	33	7	7	4 sides	3 sides
19	Eastern-Western	-	1 Fl (SVR=0.84)	2 Fl (SVR=0.67) 3 Fl (SVR=0.62)	19	14	8	0	0	33	10	10	4 sides	3 sides
20	Eastern-Western	-	1 Fl (SVR=0.91)	2 Fl (SVR=0.74) 3 Fl (SVR=0.68)	18	16	6	0	0	33	10	10	4 sides	3 sides
21	Eastern-Western	-	2 Fl (SVR=0.64)	3 Fl (SVR=0.58)	17	16	0	0	0	33	8	8	4 sides	3 sides
22	Eastern-Western	-	1 Fl (SVR=0.80)	2 Fl (SVR=0.64) 3 Fl (SVR=0.58)	17	16	0	0	0	33	8	8	4 sides	3 sides
23	Eastern-Western	-	1 Fl (SVR=0.97)	2 Fl (SVR=0.80) 3 Fl (SVR=0.75)	19	19	6	0	7	33	6	0	2 sides	2 sides

T3. The first part of the proposed remedial solutions for 23 rural housing improvement projects in accordance with their existing plans

Pattern No.	Porch		Roof ledge protrusion (m)								Canopy					Color	
	Existing	Modificatory	Existing				Modificatory				Existing	Modificatory				Existing	Modificatory
			Northern	Southern	Eastern	Western	Northern	Southern	Eastern	Western		Northern	Southern	Eastern	Western		
1	None	-	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
2	None	-	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
3	None	-	0	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
4	None	-	1	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
5	None	-	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
6	None	-	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
7	Has	None	1	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
8	Has	None	1	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
9	None	-	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
10	Has	None	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
11	None	-	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
12	None	-	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
13	None	-	1	0	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark

T4. The second part of the proposed remedial solutions for 23 rural housing improvement projects in accordance with their existing plans

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14	None	-	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
15	None	-	1	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
16	Has	None	1	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
17	Has	None	1	1	1	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
18	None	-	1	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
19	None	-	1	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
20	None	-	1	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
21	Has	None	1	1	1	1	1	0.40	1	1	None	-	-	-	-	Light	Dark
22	Has	None	1	1	1	0	1	0.40	1	1	None	-	-	-	-	Light	Dark
23	None	-	1	1	0	0	1	0.40	1	1	None	-	-	-	-	Light	Dark

T4. The second part of the proposed remedial solutions for 23 rural housing improvement projects in accordance with their existing plans

Applying corrective solutions in 23 rural housing improvement projects will lead to energy savings of at least 2% in plan number twelve and a maximum of 49% in plan number sixteen. The exact description of 23 plans is presented in Table 5.

Plan No.	Energy Consumption (kWh/m^2)		Percentage of changes
	Existing plan	Modificatory plan	
1	2 Fl: 151.26	3 Fl: 109.86	%27
2	1 Fl: 162.28	2 Fl: 114.72	%29
		3 Fl: 110.10	%32
3	1 Fl: 132.32	2 Fl: 122.25	%7
		3 Fl: 110.04	%17
4	1 Fl: 192.97	2 Fl: 158.18	%18
		3 Fl: 150.22	%22
5	1 Fl: 164.28	2 Fl: 116.27	%29
		3 Fl: 108.70	%33
6	1 Fl: 156.74	2 Fl: 114.29	%27
		3 Fl: 108.40	%30
7	2 Fl: 144.79	3 Fl: 123.01	%15
8	2 Fl: 141.63	3 Fl: 102.68	%27
9	1 Fl: 178.57	2 Fl: 122.70	%31
		3 Fl: 11471	%36
10	2 Fl: 149.96	3 Fl: 135.19	%10
11	2 Fl: 137.69	3 Fl: 105.53	%23
12	1 Fl: 162.77	2 Fl: 159.20	%2
		3 Fl: 153.30	%6
13	1 Fl: 172.18	2 Fl: 129.09	%25
		3 Fl: 123.80	%28
14	1 Fl: 185.83	2 Fl: 138.58	%25
		3 Fl: 132.52	%29
15	2 Fl: 153.29	3 Fl: 94.26	%38
16	1 Fl: 154.07	2 Fl: 91.52	%40
		3 Fl: 82.28	%46
17	1 Fl: 166.15	2 Fl: 100.47	%40
		3 Fl: 90.98	%45
18	1 Fl: 165.97	2 Fl: 94.23	%43
		3 Fl: 85.20	%49
19	1 Fl: 170.39	2 Fl: 108.54	%36
		3 Fl: 100.85	%40
20	1 Fl: 180.88	2 Fl: 112.27	%38
		3 Fl: 104.58	%42
21	2 Fl: 144.45	3 Fl: 98.89	%31
22	1 Fl: 160.32	2 Fl: 99.18	%38
		3 Fl: 89.36	%44
23	1 Fl: 150.55	2 Fl: 123.65	%18
		3 Fl: 114.26	%24

T5. Comparison of energy consumption per capita in rural housing improvement plans before and after the implementation of corrective strategies

Conclusion

The results of this study indicate that the application of changes in some physical characteristics of the proposed models for the rural housing improvement plan in the mountainous areas of Tehran province will improve their energy consumption. It is suggested that in the rural housing plan of this climatic region, the creation of a porch should be avoided and, if necessary, this space should be considered as an additional space and as a balcony next to the total volume of the building. The placement of the porch within the volume of the building, in addition to increasing the ratio of the surface to the volume of the building, causes cooling traps. A one-meter protrusion is suggested for the roof ledge on the northern, eastern and western sides, and on the southern side, this amount should be 40 cm. Windows in this climate do not require canopies. Due to the cold climate of the region, it is better to have fewer walls exposed to the outside air and their color should be dark. Also, the repetition of building floors in height reduces the ratio of surface to volume of the building and thus reduces energy consumption, and in general, in this climate, one-story building construction is not recommended due to high energy loss.

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