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Energy-conservation Considerations through a Novel Integration of Sunspace and Solar Chimney in the Terraced Rural Dwellings

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ABSTRACT

In the present study, a novel passive solar system—a designed sunspace in combination with solar chimney (SS)—is implied to work out the concerns of energy requirement in the terraced rural dwellings of Iran. Renewable plans for heating need to be implemented before regarding mechanical facilities. Due to the southern orientation of most rural homes moreover, dwelling slope it is likely to use sunlight in most hours of the day. Hence, the SS system with an area of 4 m^2 on the southern side of the building is considered. The simulation was performed through the EnergyPlus software and verified by experimental data. On the basis of the results, applying the SS system in buildings can magnify the amount of heat obtained. This is a practical plan to assist in space heating in cold months. Moreover, natural night ventilation over the SS can reduce the cooling load during hot seasons. The results additionally indicate that the highest energy-saving for heating and cooling observed in January and July respectively. Lastly, the annual economic advantage of the SS system with respect to power conservation will be 14.3% accordingly the increased cost for installing the SS will be retrieved by 8 years generally.

Keywords: Building Energy Conservation, EnergyPlus, Solar Chimney, Sunspace, Terraced Rural Area

JEL Classifications: Q20, Q41, R11

1. INTRODUCTION

Nowadays, the high demand for building construction as a result of the increasing population has been a major concern for researchers in developing countries (Agrawal, 1989; Park et al., 2015). Buildings, energy, and environment are substantial issues facing building professions across the world (Lam et al., 2006; Qian et al., 2019; Heidarinejad et al., 2017). Buildings consume lots of energy for cooling and heating globally, while the cost of the most energy types is constantly increasing (Pérez-Lombard et al., 2008). Buildings are responsible for 40% of global energy consumption and around 45% of greenhouse gases emissions all over the world (Fossati et al., 2016; Webb, 2017; Zhang et al., 2018). Heating, cooling, and lighting account for more than 70% of the energy consumption in the most type of buildings (Grimm et al., 2008; Wu and Skye, 2018; Gao et al., 2019). Because of extreme environmental pollution and the energy crisis caused by continuous operation and excessive utilization of fossil fuels, the demand for renewable energy in buildings has become an important issue (Al-Kayiem et al., 2014; Lee et al., 2015; Shi and Chew, 2012). Natural ventilation is one of the best renewable strategies to achieve sustainable and healthy environments in buildings. Natural ventilation is driven by wind or buoyancy force, or most often with a combination of them without the use of any mechanical system (Gratia and De Herde, 2004; Gan, 2010; Chenari et al., 2016). The solar chimney is a persistent strategy for reducing energy consumption by increasing the natural ventilation in the surrounding spaces (Khanal and Lei, 2011; Gan, 2010). As a simple and practical idea, solar chimney technology is known as an attractive biological design. It uses solar radiation to growth the natural ventilation in buildings, under this fact that solar energy increases the temperature and the drop in air density within the solar chimney (Lee and Strand, 2009). As a simple and practical strategy, significant consideration has been given o reduce heat gain and natural ventilation in buildings due to its potential concerning the energy demand and carbon dioxide emission (Zhai et al., 2011). For example, a study states electricity reduction rate about 10-20% in Thailand (Khedari et al., 2003). It is substantially a solar air heater with vertical or horizontal configuration as a part of the wall or ceiling, although the classification of the solar chimney can diversify according to configuration or functions (Bacharoudis et al., 2007). As well as, according to the airflow induced by the solar chimney, the requirement of a daily fan shaft in a house in Tokyo can be reduced by 90% in January and February with one meter wide solar chimney (Miyazaki et al., 2006). The solar chimney has been widely studied using experimental, analytical and computational methods. Most solar chimney studies have been adjusted to obtain optimum design solutions for enhancing natural ventilation, regarding different design parameters. The most important parameters that have been evaluated in the solar chimney researches are the height between inlet and outlet cavity, the opening areas, the chimney aspect ratio (stack height/air gap width), thermal characteristics of the absorber material and chimney inclination angle (Khanal and Lei, 2011; AboulNaga and Abdrabboh, 2000). In essence, it can be said that the operation of the solar chimney, the Trombe wall, and the double skin facade is similar to each other and is done by the buoyance natural ventilation. Trombe wall is a heavy wall with which the help of thermal mass planned for heating. The solar chimney is usually used to enhance night ventilation, although by partial modifications it can be operated for natural ventilation in the daytime. The solar chimney is utilized separately and attached to the building on the roof. The vertical type of solar chimney is also less efficient in comparison with the inclined one from the architectural aesthetics point of view (Zhai et al., 2011; Faggianelli et al., 2014; DeBlois et al., 2013a).

Recently, there has been a growing interest in the development of innovative research of solar chimney and its combination with other strategies for raising its efficiency. For instance, Aboulnaga and Abdrabboh promoted night natural ventilation using a combination of solar wall and a solar chimney. The results of their studies indicate that this new integrated system can increase the airflow rate up to 3 times as compared to the usual solar chimney (AboulNaga and Abdrabboh, 2000; Suárez-López et al., 2015; Kumar et al., 1998; DeBlois et al., 2013a). Khedari, Rachapradit in a study evaluated the efficiency of a solar chimney in one single cell with an air-conditioner. The house equipped with solar chimney reduced the average energy consumption by 20% in comparison with a usual house (Imran et al., 2015). Moreover, Maerefat and Haghighi proposed a system integrated earth-air heat exchangers coupled with solar chimneys. Considering natural ventilation, a solar chimney is used as a heat source and ground as a sink. The air in the solar chimney is getting hot and rises. Buoyancy effect motive suction for extracting the airflow from the room (Maerefat and Haghighi, 2010). A survey proposed by Li and Liu presented a numerical and experimental study about the thermal potential of a solar chimney integrated with phase change materials. The use of PCM enhanced thermal efficiency in solar chimney (Li and Liu, 2014). In order to use the Trombe wall potential for natural cooling of the buildings, Rabani and Kalantar equipped it with a solar chimney accompanied by a water spraying system. The utilization of this combination led to an increase in the thermal efficiency by about 30% (Rabani et al., 2015). Khedari and Ingkawanich suggested a roof solar chimneys combined with the photovoltaic panels. The proposed integration was economically feasible and it was measured that it can reduce the cost of energy consumption in the building (Khedari et al., 2002). As a consequence, Tavakolinia suggested an integrated passive system with a combination of a solar chimney and a wind catcher to promote natural ventilation in a room. The latest product is a natural ventilation system that improves air quality and thermal comfort levels in the room. The integrated passive chimney can be expanded for use in commercial, residential and multi-story buildings (Tavakolinia, 2011).

As we have mentioned above, many types of research combine solar chimney with other passive strategies to increase thermal efficiency and the airflow rate inside buildings. For instance, the solar chimney has been integrated with Trombe wall (Saadatian et al., 2012; Liu and Feng, 2012; Chan et al., 2010), wind catcher (Tavakolinia, 2011), double-skin façade (Quesada et al., 2012; Balocco, 2004; Azarbayjani, 2010), earth-air heat exchangers (Ramírez-Dávila et al., 2014; Maerefat and Haghighi, 2010; Li et al., 2014), etc. (Monghasemi and Vadiee, 2018). Notwithstanding, there are still many gaps in the research of enhancing the efficiency of the solar chimney by integration with other passive systems, which can be mentioned as an example of its combination with sunspace. An uncomplicated approach for absorption solar energy in the building is the use of greenhouse effects and greenhouse optimization. The greenhouse effect traps solar energy without any other element only a transparent ingredient that making it a key system in cold climates. For the utilization of solar energy as passive heating, it is necessary to consider storage, distribution, and conservation of the heat such as a sunspace (Al-Hussaini and Suen, 1998). Sunspaces are an interesting architectural solution in energy attitude of solar radiation utilization, which gives energy benefits in terms of reducing the demand for winter energy (Hestnes, 1999). Sunspaces are designed to collect solar energy to reduce the need for auxiliary energy. Solar the energy which obtains is depending on the quality of passive solar system and weather conditions (Mihalakakou, 2002). A few of solar radiation, which is transmitted through the glazed shell is absorbed by the opaque and glazed walls, and some of it is absorbed by the surrounding environment of a sunspace, and eventually, heat energy of transmitted part reach into the adjacent spaces (Oliveti et al., 2012). Sunspaces are usually used for buildings heating in winter and cold climates, taking into account reducing the building's heating loads. In the processes of sunspace designing as a passive technology in buildings, its application in summer season is not considered seeing that overheating defect in the hot time of day, consequently, the advantage of this passive system is not considered in the summer along with, in warm seasons the insulation usually separates it from the building spaces. Some solutions have been investigated to eliminate the effect of overheating. For example, it can be noted to the utilization of shadings, night ventilation, buried pipes and thermal mass in sunspace and adjacent space (Moradi and Eskandari, 2012; Mihalakakou, 2002). In this respect, we attempt to make better use of sunspace potentials in hot seasons by combining it to the solar chimney. On the other hand, the Iranian energy consumption process is highly dependent on fossil fuels, which has led to challenges such as reducing fossil fuels, economic and environmental deterioration, and regional instability. Fossil fuels supply more than 97% of energy in Iran. Hence, the administration must design a sustainable energy plan based on green and clean energy surge. On this basis, given the fact that rural areas suffer from the unstable energy system, green energy needs to be broken down into municipal and rural development programs predominantly (Afsharzade et al., 2016). In agreement with relevant studies, most of the researchers have suggested using sunspace in the buildings for cold climates. Additionally, it has highlighted that sunspace is advantageous to help the building heating mechanism in the cold seasons of the year. At the same time, the use of solar chimney has proposed to increase ventilation in the building and, more importantly, in order to improve the efficiency of the night ventilation on hot seasons of the year (Tan and Wong, 2013).

The main objective of this paper is to apply a combination of solar chimney and sunspace to create better thermal conditions in winter and summer for internal spaces. The major weakness of the sunspace is the uselessness of it in the summer season, moreover, the main defect of the solar chimney in the building is its low usage in the cold season of the year. The integration of these two passive strategies (solar chimney and sunspaces) removes these flaws relatively. In the new system, solar chimney in the cold season of the year with the help of the sunspace will increase the heating process through the roof as well as in summer nights new integrated system enhance the airflow rate in the building. With regard to the sloping and terraced texture of cold and mountains rural regions of Iran, almost all of the buildings in many hours of sunny days' benefit from sun lights. In this way applying this passive integrated strategy can reduce the heating loads in the cold season and cooling loads in the hot season and ultimately reduce the annual energy consumption of rural dwellings. The outcomes of this research can contribute to building architects and engineers with integrating the new system in houses and allow construction policymakers to make informed choices concerning how an innovative component should be utilized to induce maximum performance of the energy conservation. This paper includes five sections. In section 2, the terraced rural texture in cold and mountainous regions of Iran concisely described. Section 3 illustrates the research method and computational settings for energy simulations. Section 4 provides the simulation results. Eventually, the conclusions in section 5 are submitted.

2. THE TERRACED RURAL TEXTURE IN COLD AND MOUNTAINOUS REGIONS OF IRAN

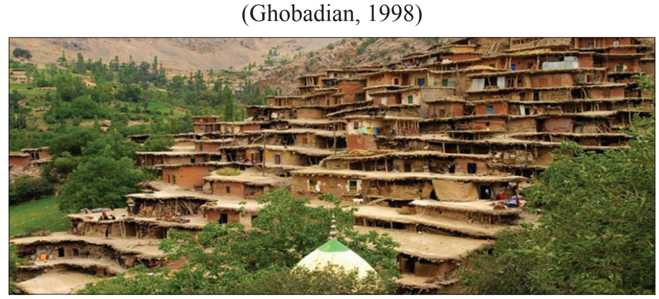
Two mountain ranges of Alborz and Zagros have caused cold and mountainous regions of Iran. Climatic conditions in these regions can be noted as hard in winter and moderate in summer, heavy snowfall, low humidity, the high-temperature variance between night and day in as much as huge roughness of the ground and lack of flat land, only villages and small towns can be expanded in the range of the mountains. Therefore, the rustic texture is mostly constructed in the middle of southern slopes of the mount and in parts of it which have a little slant. Considering cold weather in major part of the year, the maximum use of sunlight, enjoy daily temperature fluctuations, heat conservation and preventing cold wintery wind in dwelling environments are fundamental (Roshan et al., 2019; Eiraji and Namdar, 2011; Ghobadian, 1998; Moradi and Eskandari, 2012). The main characteristics of the urban and rural context can be included in small and enclosed spaces, dense texture, south-facing attached buildings and streets with low width. In this way, the contact area of residential warm spaces with the outside environment gets smaller. The urban and rural fabric is designed and implemented according to the climate and to deal with extreme cold. In the ranks of general construction, features can be pointed to low-height spaces, flat roofs, mean surface area to volume ratio forms (cubic design), least opening, shading, and yards along with thick walls (Figure 1). As a consequence of very low temperatures, the key challenge of habitat is the supply of homes heating in the winter season (Ghobadian, 1998).

In view of the fact that most of the homes are exposed to sunshine as a result of ground sloping, we can handle plenty of energy demands by utilization of passive solar heating systems such as solar window, Trombe walls, solar wall, sunspaces, etc. These structures share related working mechanism. The airflow generated by cause of temperature dissimilarity and afterward divergence in the density at inlet and outlet (the buoyancy effect) (Chan et al., 2010). However, given the fact that these systems are not required in part and parcel of the year due to no need for heating, we are trying to eliminate some of the hindrances by connecting the solar chimney and sunspace.

3. MATERIAL AND METHODS

To estimate the energy performance of the SS system, initially, dividing the construction types in accordance with field survey and adjusted statistics, typical for the domestic sector in the rural region of Iran. Next, implementing simulation patterns utilizing the EnergyPlus software to assess the energy loss for all three types of case studies both monthly and annually. EnergyPlus is a whole building energy simulation software which develops on the most useful characteristics and of BLAST and DOE-2 in The U.S. Department of Energy. It is among the most robust and

Figure 1: A view of a terraced rural texture (Masouleh village) (Ghobadian, 1998)



applied energy simulation software accessible both at scholarly and commercial grades. This simulation software presents the energy need throughout a particular time period. EnergyPlus needs chief inputs for modeling building comprising climate conditions, energy process, structure shape, and interior load. The building geometry involves the fabrics materials, direction, and shell. The following data is energy policies that incorporate the energy system calibration, assessment, set point, and performing plan. The climate conditions which encompasses weather variables like solar radiation, air temperature, air pressure, wind speed, and humidity. The internal loads involve electric means also appliances (Crawley et al., 2001; Fumo et al., 2010). consequently, verifying the EnergyPlus outputs facing the on-site field data collection. And lastly, simulate research tests and submitting pattern adjustments for elevated energy performance.

3.1. Governing Equations and the Solution Method

This study has been performed by using the EnergyPlus (v. 8) software, developed by the U.S. Department of energy; which simulates the whole energy utilization of a building (Fumo et al., 2010). The energy balance equations for zone air and surface heat transfer are two essential equations that an energy program should solve. These equations are solved by Finite Difference Methods. The energy balance equation for room air is:

$$\sum_{i=1}^{N} q_{i,c} A_i + Q_{other} - Q_{extraction} = 0 \tag{1}$$

$\sum_{i=1}^{N} q_{i,c} A_i$ is the convective heat transfer from enclosure surfaces to room air, $q_{i,c}$ is convective flux from surface i, N is the number of enclosure surfaces, A_I is the area of surface i, Q_{other} is the heat gains from lights, people, appliances, infiltration, etc. and $Q_{extraction}$, is the heat extraction rate of the room. The heat extraction rate is the same as the cooling/heating load when the room air temperature is kept constant (ΔT = 0). The convective heat fluxes are determined from the energy balance equations for the corresponding surfaces. A similar energy balance is performed for each window. The surface energy balance equation can be written as:

$$q_i^{"} + q_{ir}^{"} = \sum_{k=1}^{N} q_{ik}^{"} + q_{i,c}^{"} \tag{2}$$

$q_i^{"}$ is conductive heat flux on the surface i and $q_{ir}^{"}$ is a radiative heat flux from internal heat sources and solar radiation. The radiative heat flux is:

$$q_{ik}^{"} = h_{ik,r}(T_i - T_k) \tag{3}$$

$h_{ik,r}$ is the coefficient of linearized radiative heat transfer between surfaces i and k, T_i is the temperature of interior surface i and T_k is the temperature of interior surface k.

$$q_{i,c}^{"} = h_c(T_i - T_{room}) \tag{4}$$

h_C is the convective heat transfer coefficient and T_{room} is the room air temperature. The heat balance on the outside face is:

$$q_{sol}^{"} + q_{LWR}^{"} + q_{conv}^{"} = q_{cond}^{"} \tag{5}$$

$q_{\alpha sol}^{"}$ is the absorbed direct/diffuse solar radiation (short wavelength) heat flux and it is calculated using the procedures presented elsewhere for both the direct and diffuse incident solar radiation absorbed by the surface. The amount of solar radiation absorbed by a surface is influenced by location, surface tilt angle, use of shading surfaces, surface material properties, weather conditions, etc. A baffle blocks all shortwave radiation from reaching an underlying surface. $q_{LWR}^{"}$ is the net long-wavelength (thermal) radiation flux exchange with the surrounding air, $q_{conv}^{"}$is the convective flux exchange with outside air and $q_{cond}^{"}$ is the conduction heat flux (q/A) into the wall. Consider an enclosure consisting of building exterior surface, surrounding ground surface, and the sky. The total longwave radiative heat flux is the sum of components due to radiation exchange with the ground, sky, and air.

$$q_{LWR}^{"} = q_{ground}^{"} + q_{sky}^{"} + q_{air}^{"} \tag{6}$$

Applying the Stefan-Boltzmann Law to each component yields:

$$q_{LWR}^{"} = h_{r,ground}(T_{ground} - T_{surf}) + h_{r,sky}(T_{sky} - T_{surf}) + h_{r,air}(T_{air} - T_{surf}) \tag{7}$$

Where

$$h_{r,ground} = \frac{\varepsilon\sigma F_{ground}(T_{surf}^4 - T_{ground}^4)}{T_{surf} - T_{ground}} \tag{8}$$

$$h_{r,sky} = \frac{\varepsilon\sigma F_{sky}\beta(T_{surf}^4 - T_{sky}^4)}{T_{surf} - T_{sky}} \tag{9}$$

$$h_{r,air} = \frac{\varepsilon\sigma F_{sky}(1-\beta)(T_{surf}^4 - T_{air}^4)}{T_{surf} - T_{air}} \tag{10}$$

The longwave view factors to ground and sky are calculated with the following expressions:

$$F_{ground} = 0.5(1 - \cos\varphi) \tag{11}$$

$$F_{sky} = 0.5(1 + \cos\varphi) \tag{12}$$

$$\beta = \sqrt{0.5(1 + \cos\varphi)} \tag{13}$$

Also, outside heat transfer from surface convection is modeled using the classical formulation:

$$Q_{conv} = h_{c,ext}A(T_{surf} - T_{air}) \tag{14}$$

Q_{conv} is the rate of exterior convective heat transfer, $h_{c,ext}$ is the exterior convection coefficient, A is a surface area, T_{surf} surface temperature and T_{air} is the outdoor air temperature. These equations are solved by Finite Difference Methods (Crawley et al., 2001; Fumo et al.; 2010).

3.2. Characteristics of the Case Studies

To calculate the amount of thermal performance through the SS system, a room with the size of 3 m × 5 m ×3 m (width × length × height) was considered. This dimension is an example of the usual residential spaces in the cold rural dwelling of Iran. The room is embedded by two facing each other windows of 1.5 m*1.5 m on the northern and southern external walls. The window-to-wall ratio (WWR) area is 30% in walls approximately and the window sill height is 0.75 m. The most suitable form in this climate is the cube. In this case, the area of the envelope will be minimized concerning the building volume so that the thermal variation of the interior spaces is reduced. The study examined three different types of buildings in order to assess the impact of the establishment of a new passive strategy where can help diminish energy consumption. The first is the basic type (type A) that a room with 15 m^2 area which was defined above (type A). The second type is a room with a similar floor form to the first one which, attached with a sunspace on the southern side (type B). This dimension of the attached sunspace is 2*2 m with the area of 4 m^2. The third type is the same as previous configuration as well as, we have added a solar chimney on top of the sunspace to enhance its efficiency (Figure 2). The cavity size of the solar chimney is 1.5*0.4 m (type C). The three examination scenarios are shown in Table 1.

Due to the various thermal function of the spaces, they were divided into three categories. In the energy simulator software, the rooms as standard occupied zone and the sunspace as Semi-exterior unconditioned and moreover the solar chimney in the sort of the cavity were defined. While the building envelope regulates the flow of heat, an optimized enclosure configuration can enhance thermal performance through passive systems. Consequently, the election of materials performs a crucial function in the energy consideration conservation. As per the common architecture system in these cold regions, this room is considered to be established by medium-weight materials. Table 2 shows various layers of Material and their thermal properties. Walls, roof and floor thickness, Thermal conductivity, Density, Specific heat, and more importantly U-Value are listed in the table. These models are considered to have a 15 cm medium-weight roof and external walls with brick blocks and incorporated with a 3 cm wide insulated layer that would be 20 cm wide relatively.

3.3. Climatic Conditions and Simulation Settings Overview

For this research, weather data for Tabriz, Iran was regarded. This city is located at a latitude and longitude of 38°N, 46°E. Tabriz is controlled by the local steppe climate. In Tabriz, there is limited moisture during the year. This location is assigned as BSk by Koppen and Geiger and 4B by ASHRAE. The average temperature in Tabriz is 11°C. The average yearly rainfall is 300 mm relatively. According to the Iran climate conditions,

Figure 2: (a-b) Sections and 3D views of the SS system

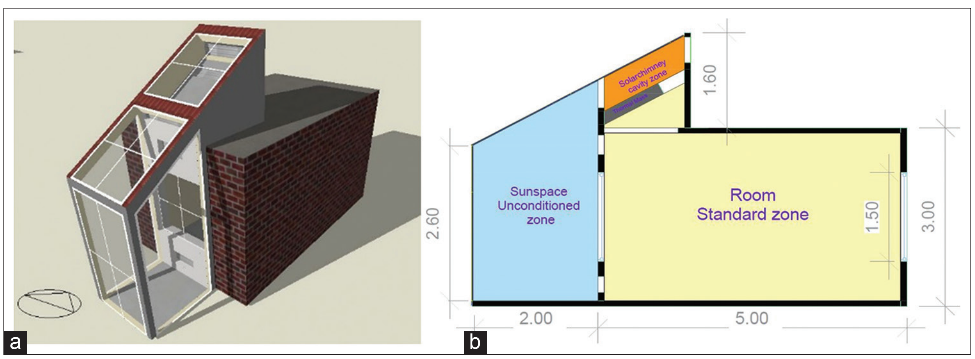
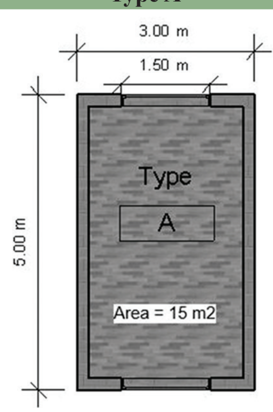
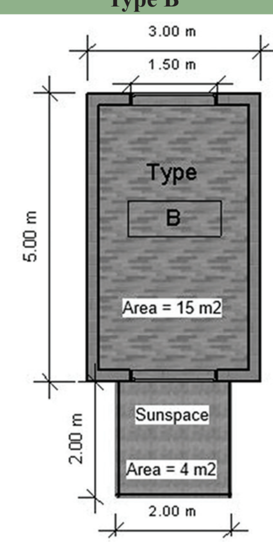
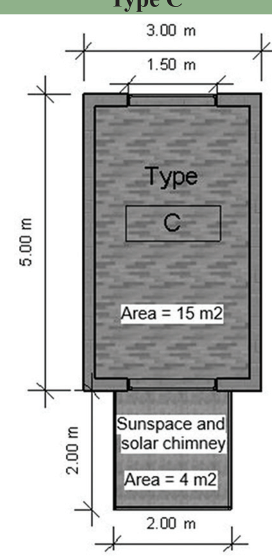


Table 1: Plans of the research scenarios

Case study	Type A	Type B	Type C
Plan			

the city of Tabriz is located at cold and mountainous zone. July is the warmest month in Tabriz with an average temperature of 24°C and the coolest is January at −1°C. The most humid month is May with an average of 40 mm of rainfall. High winter temperatures and common summer temperatures are climatic characteristics of Tabriz. Tabriz city climate data are shown in Tables 3 and 4. The weather data applied in the simulations were attained from the EnergyPlus database by the U.S. Department of Energy. The data were generated using TmyCreator by the Building and Housing Research Center (BHRC) of Iran.

In accordance with research objects, a cuboid room with both south and north confronting windows was applied to generate the building model for the EnergyPlus simulation. This building type facilitates the effect of the room geometric shape, materials and apertures, interior loads and HVAC systems, and others on the computation results. The occupancy density of residential buildings slightly is related to the lifestyle of the region. Within the Iranian rural dwellings, most of the residents would be away from house among 06:00 and 18:00 on weekdays and approximately 25% would not return home until after 21:00. Meanwhile, around 25% will return and stay home from 13:00 to15:00. Almost all the occupant would remain at the dwelling after 21:00. Most residents would stay at home on the weekend for the reason that these are state leaves. Weekday and weekend Occupancy Rate are presented in Figure 3.

An ideal air cooling system defined by EnergyPlus (Ideal load HVAC system) is used to calculate the cooling and heating energy demand for given set point temperatures. In the model outlined for this study, case studies were divided into three different zones in which each type has its particular specifications in terms of activity, HAVC systems and comfort temperature. Standard occupant zone for the room, Semi-exterior unconditioned zone to the sunspace furthermore cavity zone for the solar chimney are defined. All the values are considered in regard to the Iranian Regulation for Residential Buildings. The EnergyPlus energy simulation settings are shown in Table 5.

Table 2: Materials and its thermal properties; material are tabled from the outermost to the innermost layers

Construction elements	Layers	Thickness (m)	Thermal conductivity (W/m-K)	Density (kg/m³)	Specific heat (J/kg-K)	U-value (W/m²-K)
Walls	Brickwork	0.1	0.84	1700	800	0.457
	XPS extruded polystyrene	0.03	0.034	35	1400	
	Concrete block	0.5	0.51	1400	1000	
	Gypsum plastering	0.015	0.4	1000	950	
Roof	Asphalt	0.02	0.7	2100	1000	0.252
	Fiberboard	0.013	0.06	300	1000	
	XPS extruded polystyrene	0.12	0.034	35	1400	
Floor	Asphalt	0.02	0.7	2100	1000	0.534
	Cast concrete	0.013	1.13	2000	1000	
	XPS extruded polystyrene	0.12	0.034	35	1400	
Thermal mass (Solar chimney)	Cast concrete (dense)	0.3	1.4	2100	840	2.06

Table 3: The main climatic parameters of Tabriz city

ASHRAE climate zone	Köppen classification	Minimum dew point temperature (°C)	Maximum dew point temperature (°C)	Minimum dry bulb temperature (°C)	Minimum dry bulb occurs on	Maximum dry bulb temperature (°C)	Maximum dry bulb occurs on	Elevation (m) above sea level
4B	BSk	−25.0	18.6	−15.0	25-Janaury	37	14-July	1361

Table 4: The basic weather variables for the city of Tabriz (Monthly)

Date/Time	Outside dry-bulb temperature (°C)	Outside dew-point temperature (°C)	Direct normal solar (kWh)	Diffuse horizontal solar (kWh)	Wind speed (m/s)	Wind direction (°)	Atmospheric pressure (Pa)
January	−0.25	−1	39/1	38/4	3	111	86604/6
February	0	−6	57/8	48/9	4-March	130/2	85765/5
March	2-May	−0.142857143	55/7	75/2	4-February	123/4	85974/1
April	7-October	0/9	40	88/3	7-March	111/6	86599/2
May	16/6	8-April	57/6	109/8	3	95/9	86110
June	21/4	8-June	119/7	114/2	9-March	105/6	86394/5
July	25/6	6-July	105/5	116/8	5	109/4	85960/5
August	25/4	7	88/8	104/8	4-February	54/8	85926/1
September	21/5	2-April	95/6	81	9-February	84/2	86240/8
October	14/5	8-February	91/4	60/8	5-February	105/2	86281/9
November	3-June	0	75/7	40/9	6-Janaury	94/8	86642/8
December	0	−4	45/9	35	9-Janaury	72/1	86712/2

Figure 3: (a-b) Residential occupancy rate in the rural dwelling

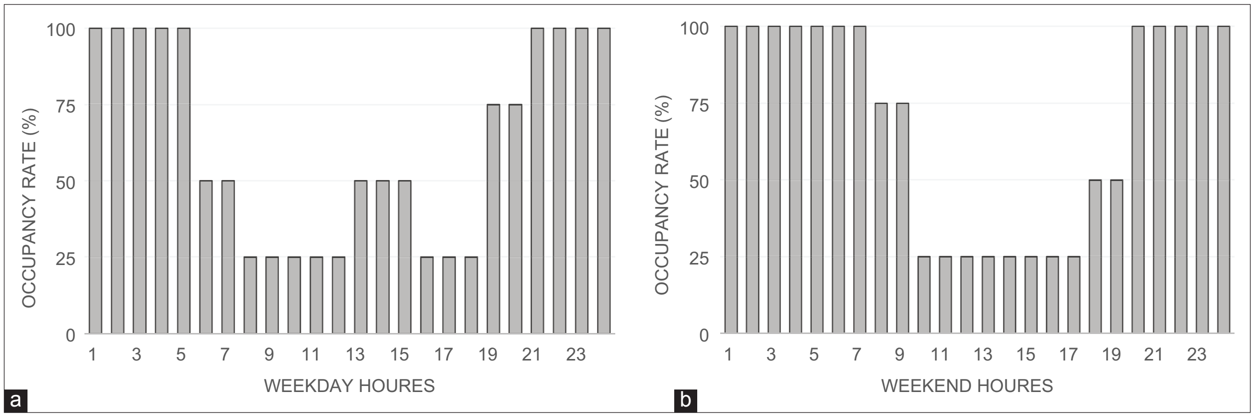


Table 5: EnergyPlus simulation settings concerning room activity

Parameter	Building model
EnergyPlus version	8.1
Inside surface convection algorithm	TARP
Outside surface convection algorithm	DOE-2
Total building floor area [m^2]	15 m^2 (5 m×3 m)
Window area (% floor area)	15%
Window area (% window to wall ratio)	25%
Windows size	2*(1.5 m×1.5 m)
Number of timesteps per hour	60
Run period	January 1-December 30, 2016
Occupancy density [people/m^2]	0.023
Metabolic rate (W/m^2)	65
Metabolic factor (men=1, women=0.85)	0.9
Winter clothing (clo)	1
Summer clothing (clo)	0.7
DHW consumption rate (l/m^2-day)	0.550
Zone HVAC template	Ideal air loads
Heating setpoint temperatures (°C)	18
Cooling setpoint temperatures (°C)	24
RH humidification setpoint (%)	10
RH dehumidification setpoint (%)	90
Infiltration rate (ac/h)	0.3
Fresh air (I/S-person)	10
Target illuminance [lx]	100

4. SIMULATION RESULTS

4.1. Model Validation

Best of our knowledge, many types of research in the globe have used EnergyPlus as energy modeling program for buildings simulation and derived the outcomes of temperature, energy need, Co_2 emission, cost, etc. Most of these investigations validate the simulation results and that indicates the authenticity of EnergyPlus for the reliable analysis of energy subjects in the buildings. Validation is required to ascertain the accuracy and reliability of the results of energy simulation. however, some of these studies have matched the results of this software with experimental and empirical data and verify the results of EnergyPlus (Loutzenhiser et al., 2007; Mateus et al., 2014; Tabares-Velasco et al., 2012; Anđelković et al., 2016; Yun and Kim, 2013; Eskandari et al., 2018). By way of example, it should be mentioned that the results of the solar chimney and sunspace researches affirm high correspondence to the experimental field data (Asadi et al., 2016; Jiménez-Xamán et al., 2019; Neves and Marques da Silva, 2018; DeBlois et al., 2013b; Wang et al., 2019; Ulpiani et al., 2019; Sánchez-Ostiz et al., 2014; Rempel et al., 2016). A comprehensive explanation of the validation study and a detailed analysis of the results can be noticed in another current paper by the authors (Eskandari et al., 2018).

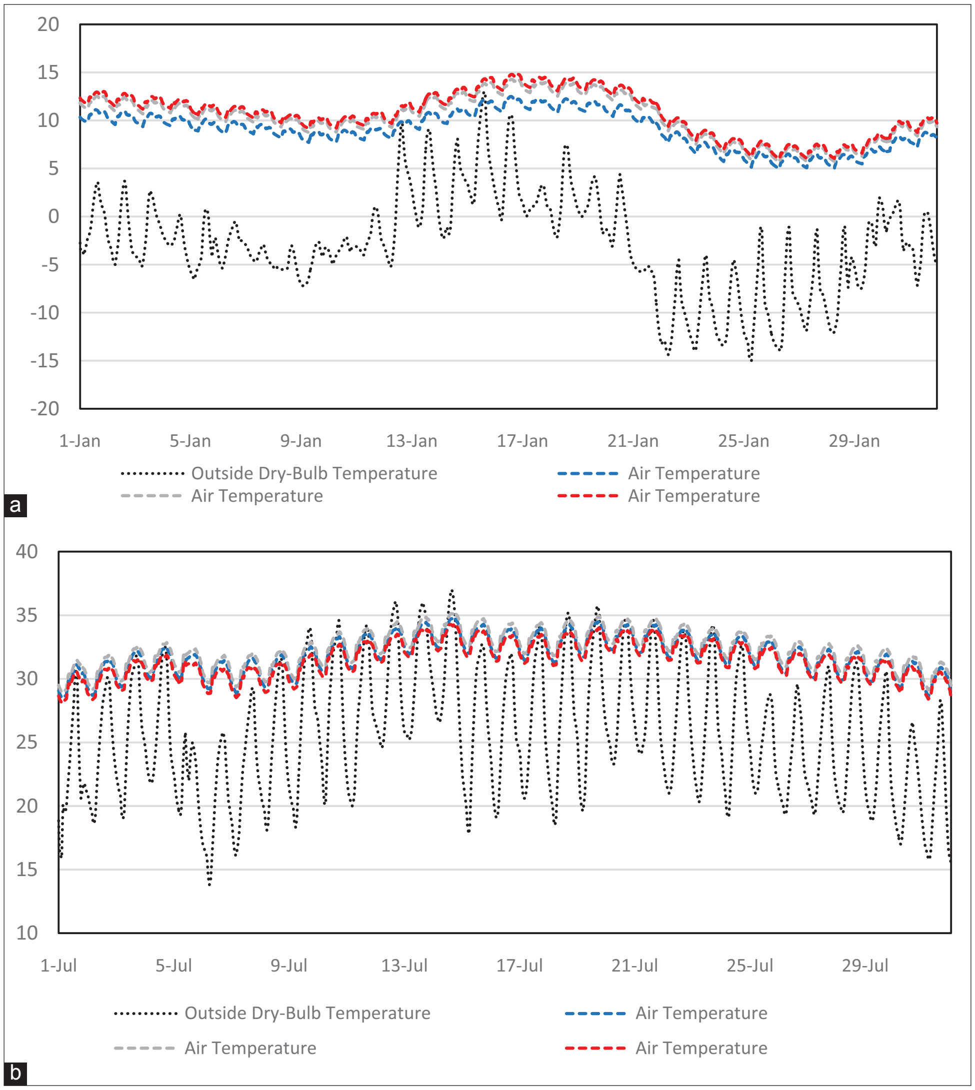
In the validation experiment, a test room with 4 × 4 m dimension, three meters' height and an opening about 1 × 1.8 m, which is approximately alike to the simulation conditions were used to validate the computer model. The room placed on the southern side of the main building. The exterior wall and window are oriented to the south. The temperature and humidity outputs resulted from the software on an hourly base throughout the week of the July 2016 interpreted and compared with experimental results. The EnergyPlus results and experimental records are in satisfying agreement among themselves. The exactness and competence of the simulation methodology are verified by gaining an error of about 6–7% between the experimental and simulation results. The accuracies of the measuring devices employed in the experiments (thermometer, hygrometer) are ±0.5°C, 3% respectively.

4.2. Simulation Results

4.2.1. Air temperature trends during winter and summer

Three buildings type with various areas and compositions were generated by EnergyPlus. On the basis of said, the software program analyzes the cooling and heating loads of the building. The simulation has been performed for a winter typical week from 17 to 23 February. The HVAC system is switched off in this case and is used only based on natural ventilation. The structure of the air temperature outlines for room and outside is drawn in Figure 4. The graphs present the temperature result for the coolest (January 1st-31st) and the hottest months (July 1st-31st) of the year. With reference to the building type configurations, the figure summarizes the outside dry-bulb air temperature and the indoor room air temperature, in relation to the equivalent values of the reference case. The temperature inclinations affirm the crucial role of solar radiation intensity and following outside air temperature on the achievement of the pleasant thermal condition in buildings. In winter, it can be regarded that the outside air temperature in Tabriz reached the lowest rate over the year, with valley even lower than −10°C. The bottom value of −15°C is achieved on 25nd of January. As long as previous research has confirmed, by application of sunspace in the winter season the mean temperature of the building raises, this research also supports this fact. The mean

Figure 4: (a-b) Air temperature during the winter and summer typical months



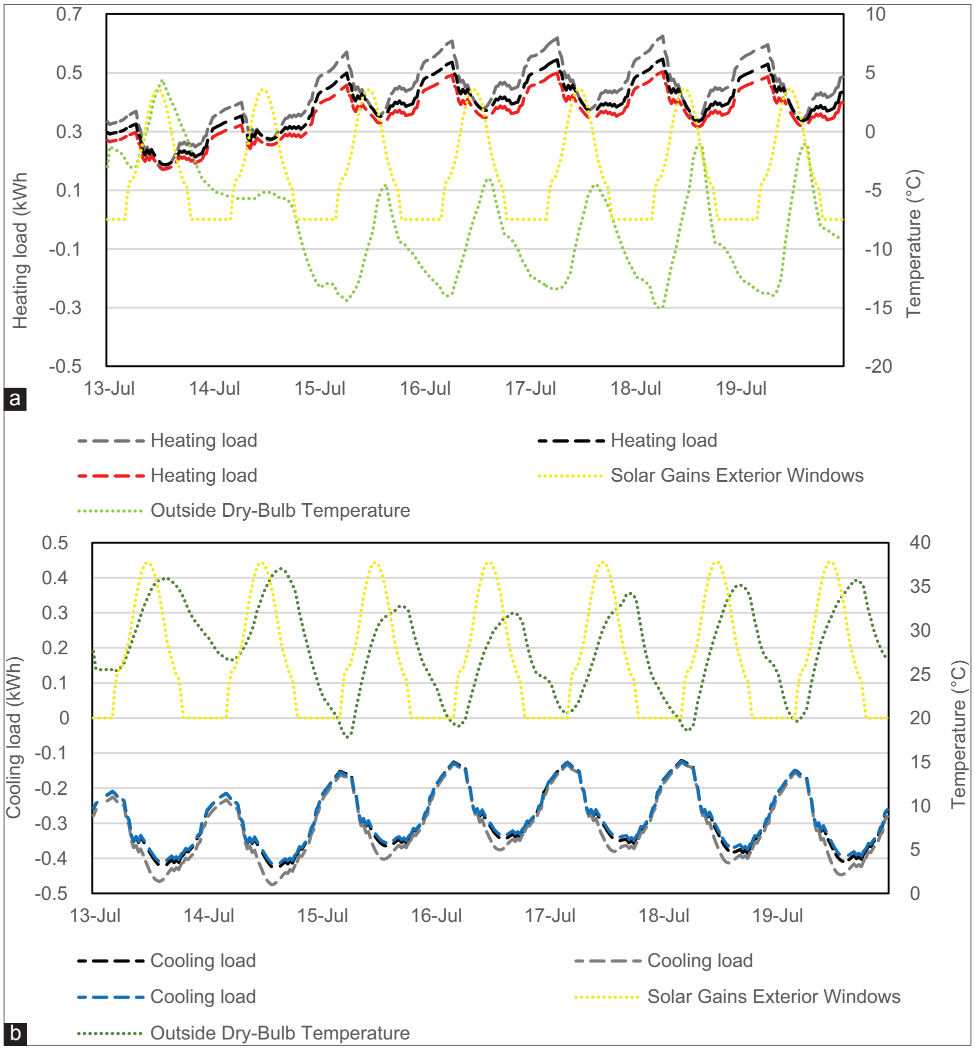
temperature variation among type A and type B is approximately 2°C. Through the utilization of solar chimney in sunspace, the room air temperature rises due to the improvement in building heating process through the roof, in such a way the figure shows. The mean temperature variation between type B and type C is about 1°C. Furthermore, in summer times it can be seen that the outside air temperature in Tabriz reached the highest rate across the year in July, with apex >30°C. The summit value of 36°C is achieved on 14^{th} of July. In the presence of intense solar radiation and by applying sunspace, room air temperature in Type 2 is higher than the reference case. This is on account of heat transfer from sunspace to the adjacent space through the wall. For type C, the air temperature is notably lower than type B. Solar chimneys can reduce the temperature by conducting night ventilation and heat storage in thermal mass which followed improving sunspace efficiency in summer. The mean room air temperature difference between type A and type B is nearly 2°C. The temperature contrast among type B and type C is around 3°C.

4.2.2. Heating and cooling loads

The weekly results for room heating load in the January cold days for all assumed cases are shown in Figure 5. As well as the solar radiation and outside air temperature, are figured in the graph for analyzing. It can be recognized that the energy loss showed the same trend for all scenarios as in the correlation with solar radiation intensity. The highest energy loss for heating can be seen in reference case A. The lowest heating loads observed in type C as we predicted. the highest variation between type A and C is viewed during peak solar radiation. This implies that the solar chimney during this period has the highest contribution to the sunspace system for heating the adjacent space. Whereas the figure shows, at night time zone sensible heating in type C is lightly lower than type B. This is as a result of the efficiency of solar chimney thermal-mass during the night time. As long as can be predicted from temperature results, the lowermost heating energy need is related to type C, B, and A, respectively.

The results for the energy loss for cooling for all samples are shown in Figure 5. It was remarked that the case with sunspace recorded the highest energy need required for cooling. The most moderate energy consumption for cooling is seen in case C. The proper performance of night natural ventilation degrades the energy loss for cooling in the case with a solar chimney although providing ventilation while the outside temperature is higher than the interior

Figure 5: (a-b) Heating and cooling loads for typical weeks in summer and winter



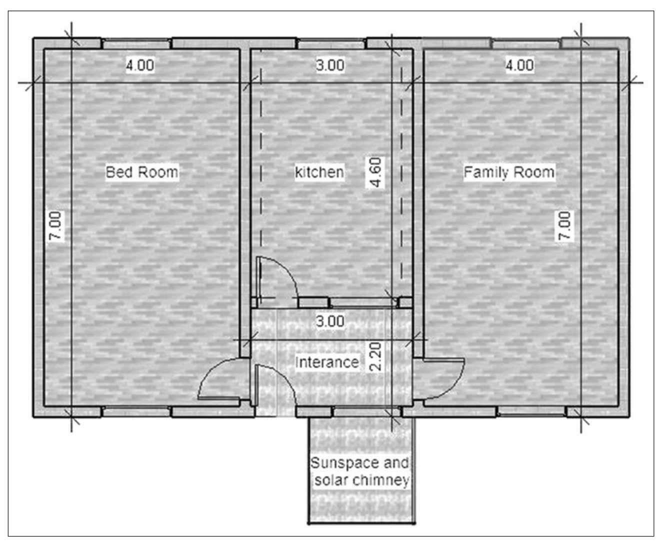
temperature results in an increase in the energy consumption for cooling as can be prognosticated from temperature outcomes, the higher cooling load is related to type B, A, and C, respectively.

4.3. Annual Energy Consumption Assessment of Rural Buildings

In the previous section, the advantage of type C was proved in accordance with two other scenarios in terms of the reduction in energy consumption. In this section, we study the efficiency of the SS system in rural buildings. Achieve this objective, a one-floor building was considered based on the classification of rural housing. The inside of a building customarily involves kitchen, bedroom, and a family room. An internal layout model with an area of 77 m² (11 m × 7 m) was planned, as displayed in Figure 6. Bathroom and toilet are often considered in the yard in rural housing. The sunspace is located on the south side of the building. With this in view, the building was simulated with sunspace and separately and the results of cooling and cooling loads were compared in Figure 7.

The building energy efficiency was investigated in regard to energy loss. Toward this study, the monthly energy consumption for cooling and heating were heeding. The consequences for

Figure 6: Layout of the simulated building



the energy loss reported to heating and cooling for all assumed cases are shown in Figure 7. January, February, November, and December recorded the highest heating energy consumption. The highest energy consumption for heating was observed in January for both two cases. The period from April to October revealed

Figure 7: (a-b) Annual energy consumption for two assumed buildings

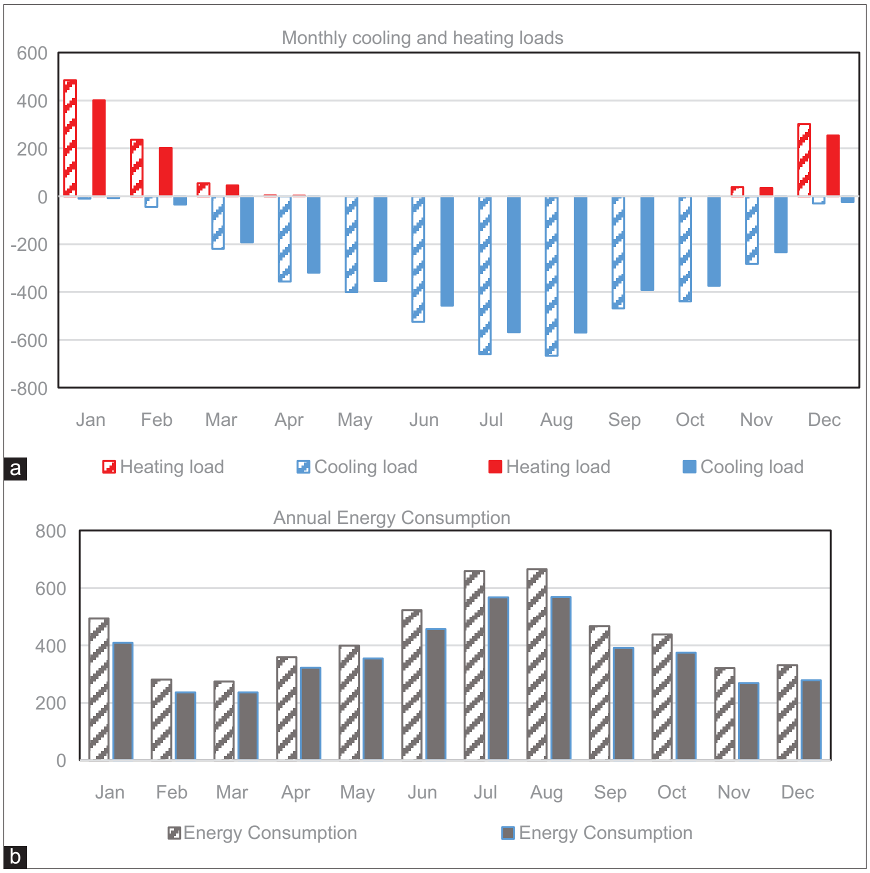


Table 6: Variation of energy cost for two case types

Case type	Annual cooling load	Annual heating load	Annual energy consumption	Annual energy cost (IRR)
Base case	4093	1121	5214	3,754,0800
SS attached	3529	939	4468	
Variation	564	182	764	
Percentage	13.7	16.2	14.3	14.3

the highest energy consumption for cooling. The highest energy using for heating was marked in August for both two cases. As the results show, the building attached with the SS has less heating and cooling loads than usual building. The highest energy loss variation for heating observed among the two scenarios is in January (83.6 kWh/month) with the rate of 18% approximately. It should be noted that the heating loads are zero from May to October. The highest energy loss variation for cooling recorded among the two scenarios is in July (90.7 kWh/month) and the lowermost is in January (1.3 kWh/month) which The rate of 15% and 14%, respectively. It is possible to deduce that the idea of the SS system enhances the efficiency of heating and cooling in buildings in all seasons.

4.4. Financial Assessment

To analyze the advantages of the SS system, in the previous section two scenarios were simulated and compared against each other. The unique unlikeness among the two types is the SS system. Accordingly, the financial conservations were resolute by matching the construction price and energy saving. The overall energy consumption point of view is presented in Table 6.

It may be considered that the annual energy consumption in the rural home by employing the SS is reduced by 724 KWh on a par with14 % annually. According to each KWh of 7200 IRR, the annual economic benefit of the SS will be 5,371,200 IRR. on the contrary, the construction and material cost of the new solar passive system is evaluated by 42,177,200 IRR. The further cost will be recovered in just about 8 years. Furthermore, by applying this system the amount of annual Co_2 production will be lessened by 4947 kg. Meanwhile, the sunspace area can be used for agricultural application and leads to entrepreneurial development in the rural dwelling. Iran has 5.9 million rural houses which around One-fourth of them are in cold regions. Provided cuts thereof approved this design and it gained popularity in the cold zones of Iran, the capability of energy conservations is huge beside Co_2 production in the Iranian building sector is degraded.

5. CONCLUSION

To subdue the energy loss of rural homes and improve the indoor thermal conditions, this research carried out a proof of concept.

First, a room with a southern window in three configurations was designed: usual room, with a sunspace along with integration between sunspace and solar chimney (SS). Afterward, the impact of these passive solar systems on energy consumption was assessed. Ultimately, based on the aforementioned inquiry, the SS was attached to a rural house to improve the indoor thermal conditions and annual energy cost. As listed below findings have been acquired:

- Considering this fact that the SS should be exposed to the proper sunlight and wind flow for more reliable performance, supposed to be designed in areas including these characteristics. Thereby the terraced rural area according to its form denotes one of the most efficient places
- The outcomes indicate that the SS system decreases the indoor temperature by about 2°C in hot seasons and increases it 3°C in the cold months needless HVAC. Implementing the SS system can amplify the amount of heat obtained. This is a practical approach to degrade space heating in cold seasons. Due to the high correlation between the thermal efficiency of the SS and the sunlight, results stated that its best performance was observed during the hot time of days and hot months of the year
- With utilization SS and night natural ventilation in buildings the cooling load of the building during hot seasons reduced. The application of proper thermal mass in the solar chimney has a significant function in the performance of night ventilation and the SS system conclusively
- The highest energy loss variation between two cases in favor of heating and cooling observed in January and July respectively. Furthermore, the highest efficiency of the SS observed in July concerning reducing energy consumption. Could be concluded that during peak hours of energy consumption, the SS system has the highest efficiency and will be the most helpful
- As regards the annual economic benefit of SS concerning energy saving will be 14.3% in this way the extra cost for installing the SS in buildings will be recovered in just about 8 years. This results is only assessed for a SS with 4 m2 area and may vary by modifying its area.

The possibility for the use of passive solar tactics in the rural dwelling is confirmed by the outcomes of this study. This is a pilot study and many variables affecting the SS performance which should consider in the future researches. The consequences of this study can contribute to building architects and engineers and it is appropriate to consider as worthy referential knowledge for the initial design process. Taking everything into account, this research offers a critical idea for degrading energy needs in buildings.

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