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Evaluation of the energy demand in the building by using a sunspace in combination with solar chimney

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ABSTRACT

Due to the expansion of the energy crisis in the world, the use of methods that lead to the reduction of energy consumption in buildings has become an important challenge. In this regard, various methods have been presented, one of which is the use of passive systems based on the sun. The passive solar system, which consists of a sunspace in combination with a solar chimney, can be effective in heating of space in the cold climate. However, investigation of using this system on building energy consumption is one of the main research gaps in this area. Accordingly, the main goal of this research is to evaluate the amount of energy consumption in a passive solar system consisting of a sunspace in combination with a solar chimney. In this regard, the research question can be asked as follows: How can the use of the solar system on the south side of the building in a cold climate affect the reduction of the building's energy consumption? This research is based on the simulation of a building in the Energy plus software. In this research three case studies are selected as follows: a single room with an opening in its south façade (Type A); a single room with a sunspace located in its south façade (Type B); and a single room with a sunspace and a solar chimney located in its south façade (Type C). Indoor air temperature, cooling and heating load of the building, and the financial assessment are three parameters which analyzed in per case studies. The results show that the use of sunspace and solar chimney on the south front of buildings in cold climates can bring better energy efficiency. This system can reduce inside air temperature by 3 °C in January and increase it 2 °C in July compared to Type A. its heating and cooling loads are less than two other case studies and at last, the highest energy saving is achieved in Type C building, so that the return on investment from saving energy consumption in this building will be about 8 years.

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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). 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, Bravo and Castilla, 2016). Buildings are responsible for 40 percent of global energy consumption and around 45 percent of greenhouse gases emissions all over the world (Fossati et al., 2016, Webb, 2017, Hwang et al., 2019, Escrivá-Escrivá et al., 2019). Heating, cooling, and lighting account for more than 70 percent of the energy consumption in the most type of buildings (Grimm et al., 2008, Hajali Zadeh, 2023).

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 and Gilani., 2014, Lee et al., 2015, Shi and Chew, 2012, Tommasi et al., 2018, Reus-Netto et al., 2019). 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 (Fig. 1) (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, Hidaka et al., 2018; Zhai et al., 2011; 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).

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, Salata et al., 2015, Klimeš et al., 2018; Khakzand et al., 2024; Zhai et al., 2011, Faggianelli et al., 2014).

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 three times as compared to the usual solar chimney (AboulNaga and Abdrabboh, 2000). 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 percent in comparison with a usual house (Imran et al., 2015). Moreover, Maerefat and Haghghi 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 Haghghi, 2010). A survey proposed by li and Liu presented a numerical and experimen-

tal 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 percent (Rabani et al., 2015). Khedari and Ingkawanich suggested a roof solar chimney 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 (Farzaneh, 2020). 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, 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 Vadiie, 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. 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 energy which obtains is depending on the quality of passive solar system and weather conditions (Mihalakakou, 2002, Lage-Cal et al., 2018). 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 (Fig. 2).

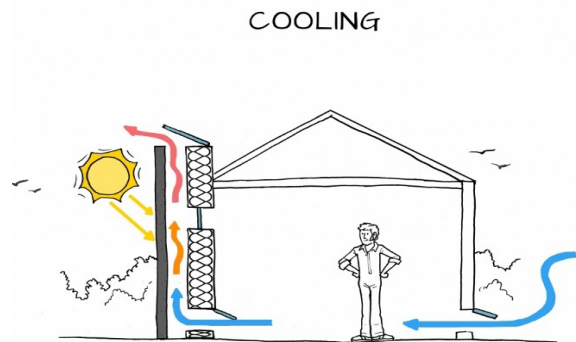


Figure 1: Application of solar chimney as a passive system in the building

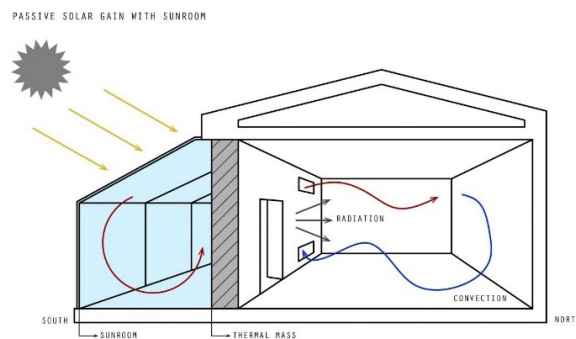


Figure 2: Application of sunspace as a passive system in the building

Based on mentioned above, the present study investigates the use of two passive systems, sunspace and solar chimney, in reducing energy consumption in buildings. Based on this, three types of buildings have been selected as research case studies as follows:

- Type A: This pattern, which is introduced as the basic pattern, consists of a simple room with a north-south extension, and an opening on its south side;
- Type B: In this pattern, a sunspace is added to the basic pattern.
- Type C: in this model, in addition to the sunspace, a solar chimney is also added to the basic model.

Each of case studies is simulated in the Energy Plus software and the results are extracted in relation to the three parameters of indoor air temperature, cooling and heating load of the building, and finally financial analysis. It should be noted that all simulations will be done in July and January. Finally, the best case were indicators.

This paper includes four sections. Section 2 illustrates the research method and computational settings for energy simulations. Section 3 provides the simulation results. Eventually, the conclusions in section 4 are submitted.

MATERIALS AND METHODS

As mentioned above, the main goal of this research is to analyze the role of using the solar chimney system in combination with sunspace in order to reduce energy consumption in the building. For this purpose, a single room in a

rural environment in the cold climate of Iran was chosen as the base case, and by adding sunspace and solar chimney, two other cases were obtained as research cases studies. The characteristics of the case studies are explained in detail in Section 2.2. After determining the case studies, they were simulated using Energy Plus software. This 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 (Tarkalam et al., 2023). It is among the most robust and applied energy simulation software accessible both at scholarly and commercial grades. This simulation software presents the energy need throughout a particular time period. Energy Plus needs chief inputs for modeling building comprising climate conditions, energy process, structure shape, and interior load (Crawley et al., 2001, Fumo et al., 2010).

The variables examined in this research include temperature analysis in winter and summer seasons, changes in cooling and heating load of the building in the mentioned periods, and finally financial assesment of the selected sample. The consensual frame work and the reserch stages are presented as follows (Fig. 3):

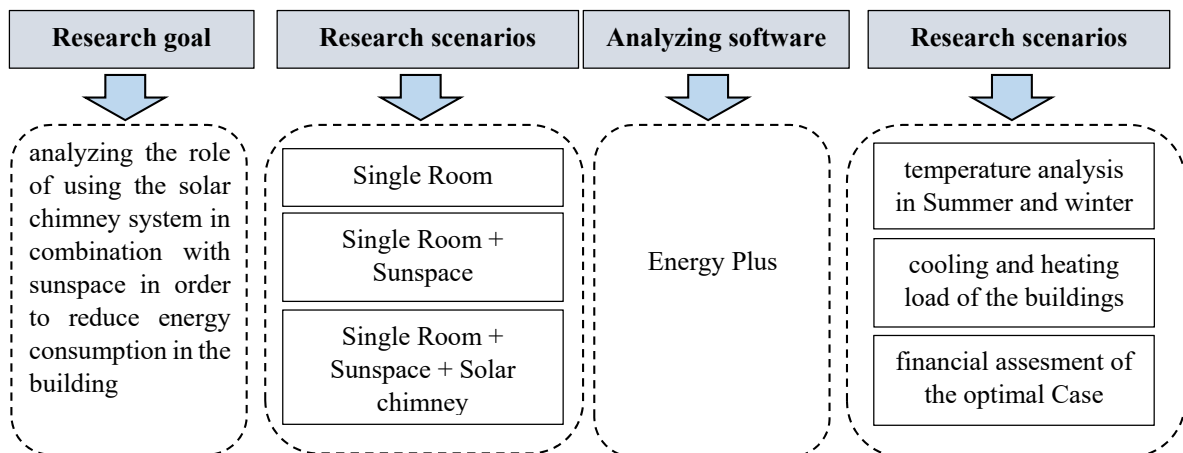


Figure 3: Conceptual frame work

2.1. 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:

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

$\sum_{i=1}^N q_{i,c} A_i$ 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 ($\Delta T = 0$). 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:

$$q_i'' + q_{ir}'' = \sum_{k=1}^N q_{ik}'' + q_{i,c}'' \quad (2)$$

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:

$$q_{ik}'' = h_{ik,r} (T_i - T_k) \quad (3)$$

$h_{ik,r}$ 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.

$$q_{i,c}'' = h_c (T_i - T_{room}) \quad (4)$$

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

$$q_{sol}'' + q_{LWR}'' + q_{conv}'' = q_{cond}'' \quad (5)$$

$q_{\alpha,sol}''$ 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.

$$q_{LWR}'' = q_{ground}'' + q_{sky}'' + q_{air}'' \quad (6)$$

Applying the Stefan-Boltzmann Law to each component yields:

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

Where

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

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

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

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

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

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

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

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

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

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 tempera-

ture and T_{air} is the outdoor air temperature. These equations are solved by Finite Difference Methods (Crawley et al., 2001, Fumo et al., 2010).

2.2. Characteristics of the case studies

To calculate the amount of the thermal performance through the SCh system, a room with the size of 3m × 5m × 3m (width × length × height) was considered as the reference case. These dimensions are 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*1.5 m² on the northern and southern external walls. The window-to-wall ratio (WWR) area is 30 percent for each window and their sill height are 0.75 m. The study exam-

Table 1: The specifications of research case studies.

Case Study	Type A	Type B	Type c
Plan			
Section			

ined 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 as follow:

Type A: This is known as the basic type and is compounded of a single room with 15 m² area.

Type B: The second type is a room with a similar floor form to the first one which, attached with a sunspace on the southern side. The dimension of the attached sunspace is 2*2 m².

Type C: The third type is the same as Type B configuration as well as, we have added a solar chimney on top of the sunspace to enhance its efficiency. The cavity size of the solar chimney is 1.5*0.4 m².

The specifications of the three cases along with their plans and sections are presented 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.

2.3. Climatic conditions and simulation settings overview

The area investigated in this research includes the Basmonj village, 35 km away from Tabriz city (Fig. 4). Considering that there is no weather information related to this village, due to the similarity of its climatic data with Tabriz, the climatic data of this city was used as the basis for simulation. The average temperature in Tabriz is 11 °C and its average yearly rainfall is 300 mm relatively. According to the Iran climate conditions, 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

Table 2: Materials and its thermal properties used in the case studies.

construction elements	Layers	Thickness m	Thermal conductivity W/m-K	Density kg/m ³	Specific heat J/kg-K	U-Value W/m ² -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

and the coolest is January at -1°C . The most humid month is May with an average of 40mm of rainfall. high winter temperatures and common summer temperatures are climatic characteristics of Tabriz. Tabriz city climate data are shown in Table 3 and 4. The weather data applied in the

simulations were attained from the energy plus database by the U.S. Department of Energy. The data were generated using TmyCreator by the Building and Housing Research Center (BHRC) of Iran.

Table 3: The main climatic parameters of Tabriz city

ASHRAE Climate Zone	Köppen Classification	Minimum Dew Point Temperature ($^{\circ}\text{C}$)	Maximum Dew Point Temperature ($^{\circ}\text{C}$)	Minimum Dry Bulb Temperature ($^{\circ}\text{C}$)	Minimum Dry Bulb Occurs on	Maximum Dry Bulb Temperature ($^{\circ}\text{C}$)	Maximum Dry Bulb Occurs on	Elevation (m) above sea level
4B	BSk	-25.0	18.6	-15.0	Jan-25	37.0	Jul-14	1361

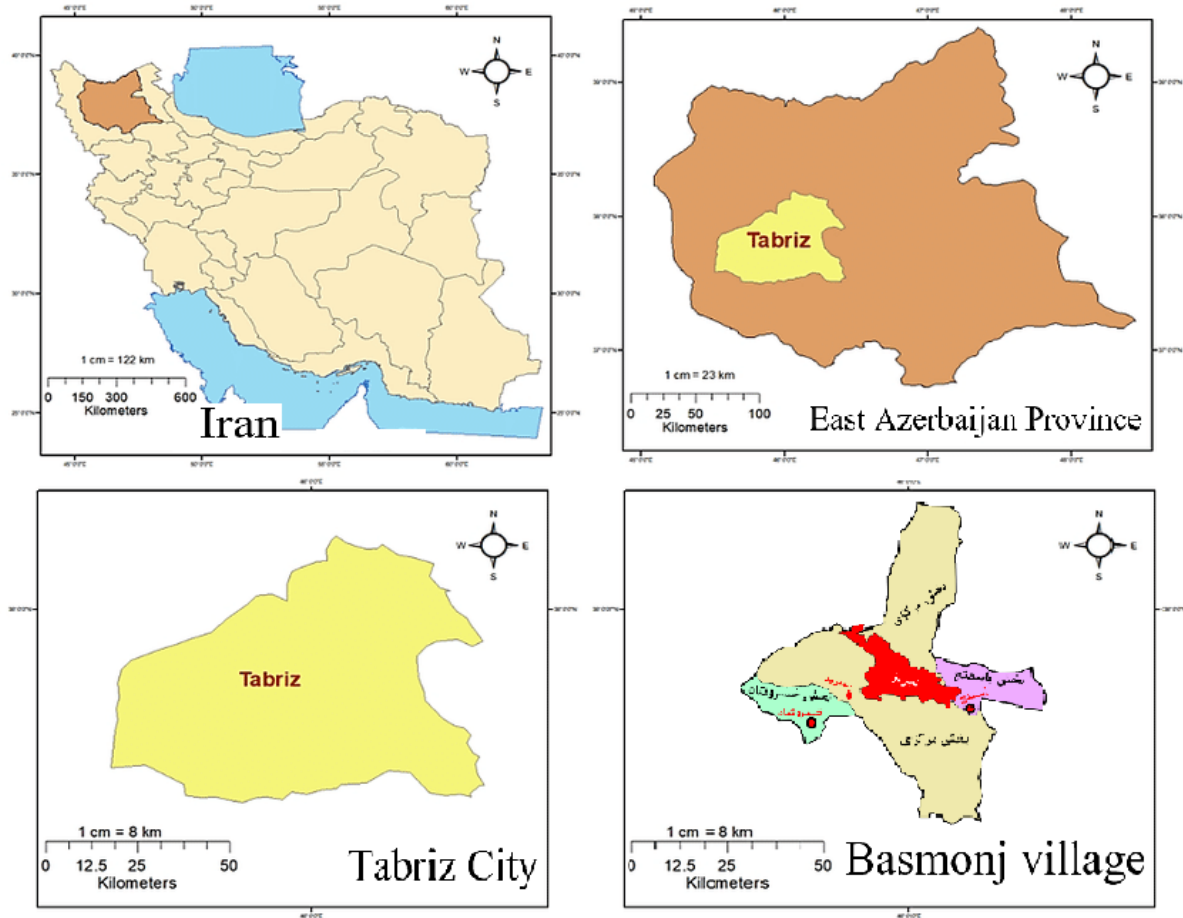


Figure 4: Location of Basmonj village near to Tabriz city in East Azerbaijan Province

In accordance with research objects, a cuboid room with both south and north confronting windows was applied to generate the building model for the Energy Plus 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 to 15:00. 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 Fig 5.

2.4. Soft wear settings

An ideal air-cooling system defined by Energy Plus (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,

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)
Jan	-2/8	-7/7	39/1	38/4	3	111	86604/6
Feb	-0/9	-6/1	57/8	48/9	3/4	130/2	85765/5
Mar	5/2	-1/7	55/7	75/2	2/4	123/4	85974/1
Apr	10/7	0/9	40	88/3	3/7	111/6	86599/2
May	16/6	4/8	57/6	109/8	3	95/9	86110
Jun	21/4	6/8	119/7	114/2	3/9	105/6	86394/5
Jul	25/6	7/6	105/5	116/8	5	109/4	85960/5
Aug	25/4	7	88/8	104/8	2/4	54/8	85926/1
Sep	21/5	4/2	95/6	81	2/9	84/2	86240/8
Oct	14/5	2/8	91/4	60/8	2/5	105/2	86281/9
Nov	6/3	-0/1	75/7	40/9	1/6	94/8	86642/8
Dec	-0/4	-4/1	45/9	35	1/9	72/1	86712/2

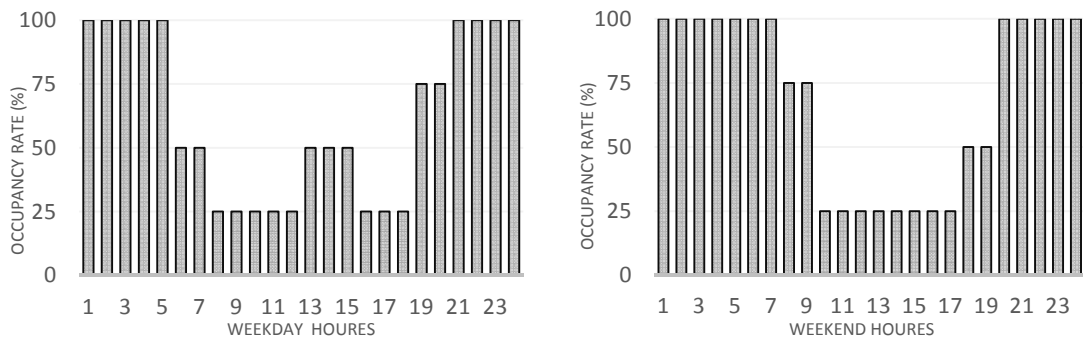


Figure 5: Residential occupancy rate in the rural dwelling

HAVC systems and comfort temperature. standard occupant zone for the room, Semi-exterior unconditioned zone to the sunspace further-more 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.

Soft wear validation

Many different researches have used EnergyPlus as energy modeling program for buildings simulation and derived the outcomes of temperature, energy need, co2 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 (Loutzenhisser 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, de Oliveira Neves and Marques da Silva, 2018, DeBlois et al., 2013, 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).

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 to 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 (l/S-person)	10
Target Illuminance [lx]	100

In the validation experiment, a test room with 4×4 m dimension, three meters' height and an opening about 1×1.8m, 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 energy plus 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.

DISCUSSION AND FINDINGS

Air temperature trends during winter and summer

In this section the air temperature inside each case studies have been investigated. The simulation has been performed for a winter typical week from 17 to 23 Feb. The HVAC system is switched off and is used only based on natural ventilation. The structure of the air temperature outlines for room and outside is drawn in Fig 6. the graphs present the temperature result for the coolest (Jan 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 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 greater than 30 C. The summit value of 36 C is achieved on 14nd 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.

Heating and cooling loads

The weekly results for room heating load in the January cold days for all assumed cases are shown in Fig 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 pre-

dicted 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 Fig 7. 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

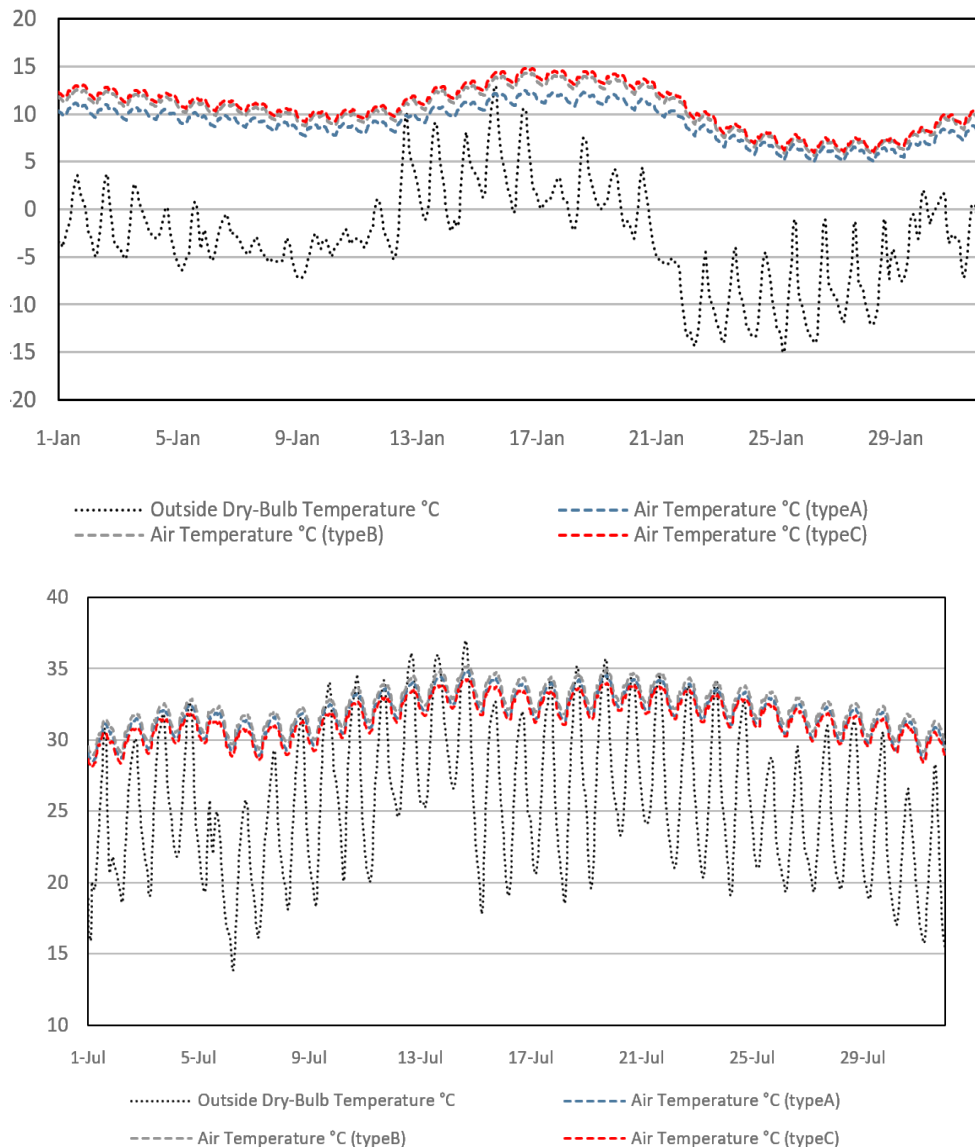


Fig. 6: Air temperature during the winter and summer typical months.

cooling in the case with a solar chimney although providing ventilation while the outside temperature is higher than the interior 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.

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

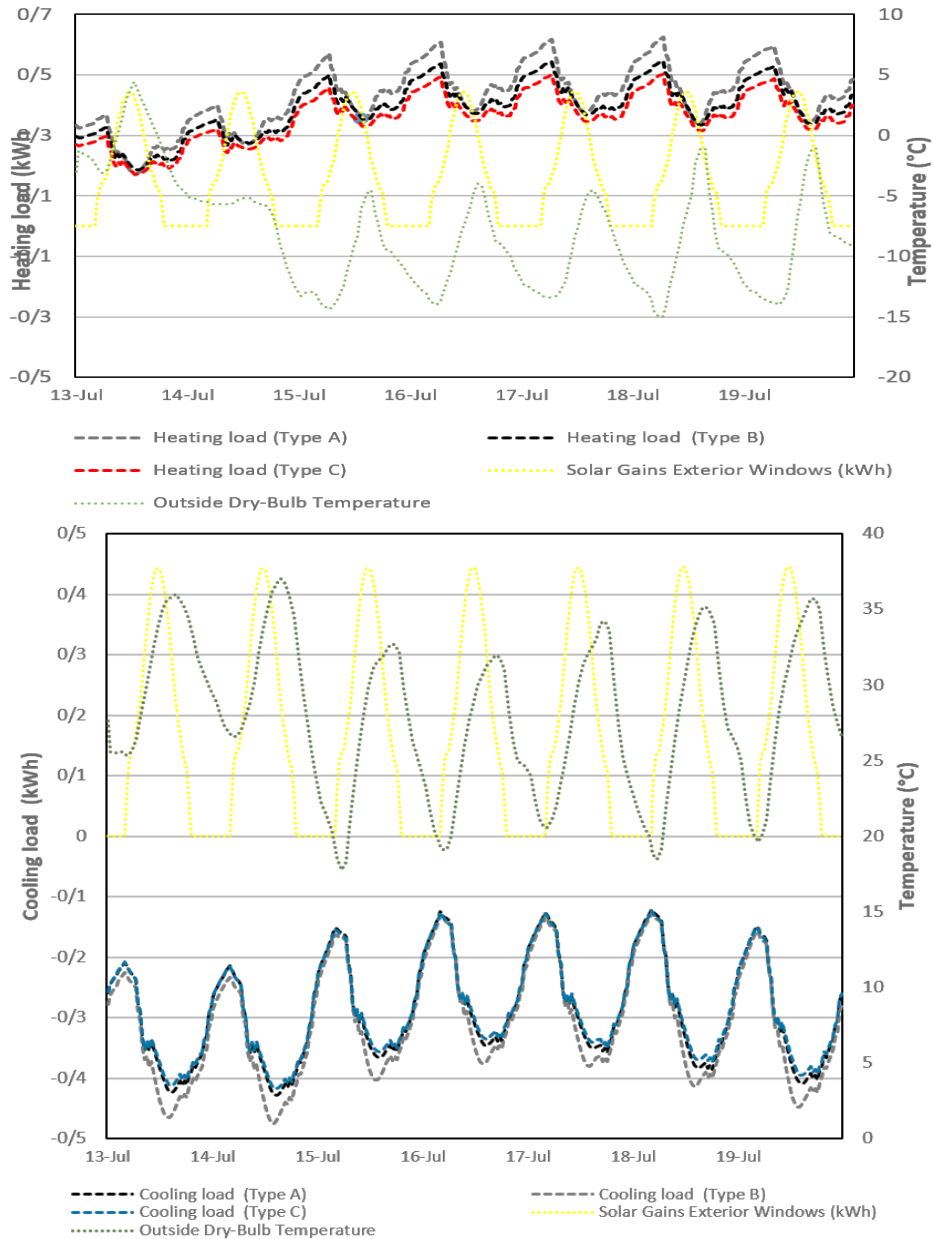


Figure 7: Heating and Cooling loads for typical weeks in summer and winter.

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 with 14 % 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 co₂ 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 CO₂ production in the Iranian building sector is degraded.

RESULT AND CONCLUSION

The purpose of this research is to investigate the role of using sunspace and solar chimney in reducing energy consumption in rural residential buildings in the cold climate of Iran. Based on this, three building models were selected as case studies as follow: 1- The simple building including a simple room and an opening on its south side (introduced as type A in this research); 2- A simple building with a sunspace attached on its southern front (introduced as type B in this research) and 3- A simple building with a sunspace and a solar chimney on attached its southern front (which in this research It is intro-

duced as type C); Case studies were simulated in Energy plus software for the two months of January and July, and three parameters of air temperature, cooling and heating load, and financial analysis were performed for each of the case studies. The most important findings of this research are mentioned as follows:

Analysis of the air temperature inside the building

- Using an only sunspace on the south front of the building (Type B) has increased the air inside the building by 2 °C compared to Type A in January. This is despite the fact that the thermal performance of this building is not very favorable in summer; So that the air temperature inside Type B in July is 2 °C warmer than Type A.
- The use of Sunspace and solar chimney simultaneously in Type C building has increased the air temperature in the room by 3 °C compared to Type A in January. The thermal performance of this building is also suitable in the summer season, so that a 2-degree temperature decrease in the interior compared to the Type A building can be seen in July.

Analysis of cooling and heating load inside the building

- The lowest heating load in winter is formed in Type C, Type B and Type A, respectively.
- The lowest cooling load in summer is formed in Type C, Type A and Type B respectively.

Financial assessment

- The highest energy saving is achieved in Type C building, so that the return on investment from saving energy consumption in this building will be about 8 years.

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%

According to the results mentioned above, it can be concluded that the use of sunspace and solar chimney on the south front of buildings in cold climates can bring better energy efficiency. It should be noted that using this system in the building in the summer by improving the natural ventilation inside the building reduces the temperature inside the building and thus reduces the cooling load of the building. In winter, this system absorbs more heat from the sunspace and the thermal mass of the solar chimney and transfers it into the space. Accordingly, it increases the temperature of the interior space and thus reduces the heating load of the building. 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. 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 buildings. Figure 8 shows a three-dimensional image of the use of Sunspace and solar chimney in the building considered in this research (Type C).

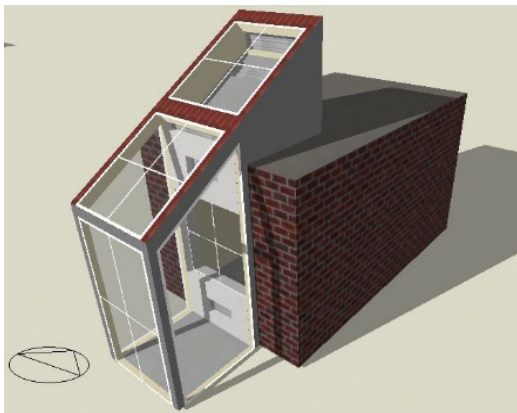


Figure.8: 3D views of using Sunspace and solar chimney in the building (Type C)

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