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REVIEW ARTICLE

Arun Kumar NANDA, C K PANIGRAHI

A state-of-the-art review of solar passive building system for heating or cooling purpose

Abstract The major portion of energy in a building is consumed by heating, ventilating, and air-conditioning (HVAC). The traditional heating and cooling systems contribute greatly to the emission of greenhouse gases, especially carbon dioxide. Four different ways, i.e., Trombe wall, solar chimney, unglazed transpired solar façade, and solar roof, are adopted for solar heating. Similarly, two major ways, i.e., evaporative cooling and building integrated evaporative cooling are adopted for cooling of the building. Therefore, an attempt has been made in this paper to compile the developments of solar heating and cooling technologies in a building.

Keywords HVAC, heating, cooling, solar heating, carbon dioxide (CO_2) emissions

1 Introduction

The requirement of energy in the building division is 35.3% of the total available energy [1]. The energy consumed by the heating, ventilating, and air-conditioning (HVAC) systems is found to be significantly high in buildings. The total amount of energy consumption of the HVAC in buildings is very high because it is intricately related to the local climate. The provision of space heating in buildings is the No. 1 demand in cold weather and space cooling in hot weather. Report reveals that half of the energy used in the service sector is used for space heating in England in 2004 [2,3]. Study also indicates that about half of the total service energy is used for space cooling in Shanghai, China [1]. It is observed that the HVAC systems have a great impact on the emission of greenhouse gases [1]. At present, alternate energy sources emerge as a prominent source of energy to fulfill the demand of space heating and cooling as presented in the Table 1.

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Arun Kumar NANDA (✉)
Birla Institute of Technology, Mesra, Ranchiranchi 835215, India
E-mail: bit2014@rediffmail.com

C K PANIGRAHI
School of Electrical Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar 751024, India

2 Review of natural heating and airing

Passive solar heating and passive ventilation technologies have similar working mechanism as shown in Fig. 1. The air flow takes place due to buoyancy. Table 2 represents the concise summary of the most important literature review of passive façade and roof design.

Four different ways, i.e., Trombe wall, solar chimney, unglazed transpired solar façade, and solar roof, are adopted for solar air heating.

The Trombe wall is an ordinary wall which is externally glazed with air channels provided in between. The purpose of this arrangement is to absorb and store solar thermal energy, some portions of which are to be used for inside compartment of the house [11]. It is used for cooling in the summer by the proper circulation of air. However, without adjustable damper, both the upper and lower vent should be closed down if outside temperature is high as compared to inside temperature [12]. The e-coating applied on the spandrel glass has been proposed to reduce the thermal losses by Richman and Pressnail [13]. It is also found that the double glazing arrangement raises the flow rate of the air by 11%–17% [14]. A new concept of photovoltaic Trombe wall has been introduced [15], which absorbs the heat and decreases the temperature of the solar photovoltaic cell. A study on the application of insulation on the storage wall has been conducted and it is found that it has no adverse effect on the comfort level [16]. The composite Trombe–Michel wall is the same as an ordinary Trombe wall except one extra insulating wall in the back wall. The phase change material can be used in the place of the Trombe wall, which will increase the thermal storage capacity of the system [17–19].

The purpose of using the solar chimney is to develop the

Table 1 Solar heating and cooling technologies by active and passive designs

	Heating	Cooling
Active solar design (Uses electrical or mechanical equipment)	By the help of solar collector heating of the required fluid occurred. Hot fluid is used for space heating	Here solar energy is used as power source of air conditioner
Passive solar design	It will absorb the heat from solar passive energy	It generates and processes airflows so that it has a cooling effect

Table 2 Summary of some of the selected previous researches

Design of roof	Features	Temperature	Cost and energy analysis	Benefits	References
Solar chimney	Vertical similar to Trombe wall	Exhaust air = 39°C Indoor air = 30°C	N.A	Increase in temperature and air velocity	[4]
Solar wall	Similar to Trombe wall	Exhaust air = 42°C Indoor air = 28°C	N.A	Temperature increases with increasing wall height and decreasing gap.	[5]
Double facades	(i) outer skin: glaze (ii) outer skin: PV panel	N.A	Increased electricity conversion efficiency	Increased efficiency of PV cell	[6]
Single sided heated solar chimney	In hot and humid climate, it includes the study during clear sky.	(i) Exhaust air = 38°C Indoor air = 33°C (ii) Exhaust air = 33°C Indoor air = 32°C	N.A	It can reduce indoor temperature by 1°C–3.5°C.	[7]
Roof solar collector	Air gap and roof solar collector	N.A	Small cost	Big air gap and equal size of openings produce higher air flow rate.	[8]
Façade/roof design	**Special features**	**Temperature benefits**	**Cost and energy analysis**	**Benefits**	**References**
Roof integrated water solar collector	Combining of conventional roof and flat plate solar collector	N.A	150 to 200 USD/m^2 compared to 160–220 USD/m^2 of conventional air conditioner	Able to control heat delivery to adapt with the environmental condition.	[9]
Roof solar collector	Single and double pass design	Single pass supply air = 12°C Air = 8°C	Choosing a suitable fan is important to reduce initial investment and running cost	Instantaneous efficiency of double pass is 10% higher than single pass collector whether it is spacing or natural ventilation	[10]

Notes: I–solar intensity; T_a–ambient air temperature; N.A–not applicable

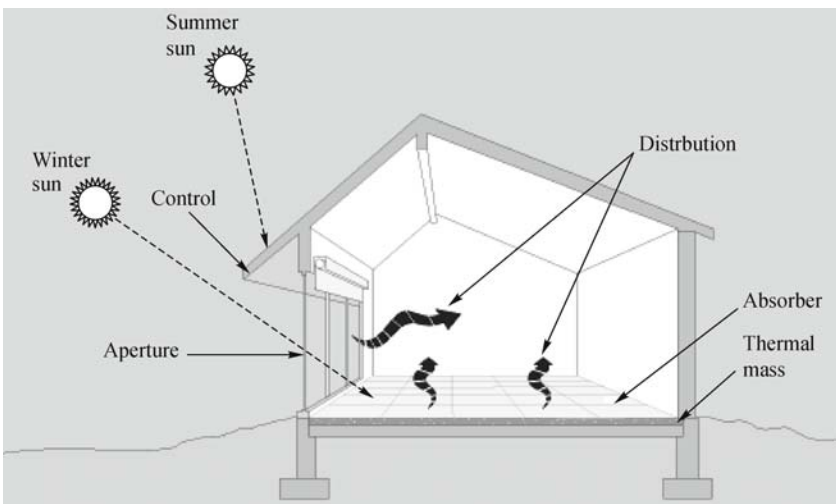

Fig. 1 Schematic diagram of passive solar design (iklimnet.com)

movement of inside air. It is governed by the density difference between the inlet and the outlet of the chimney. The three different modes are presented by Miyazaki et al. [20]. However, it is not attractive externally. Therefore, to increase the height, an adjustment in both types may be preferred [21]. The major component of the system, as illustrated in Fig. 2, is two passive solar air heaters [22]. The earth air heat exchange concept is applied, as depicted in Fig. 3. The arrangement of the pipe is parallel and buried in the ground [23] to provide cooling for the building.

By using an exhaust fan, hot air is extracted and used for space heating [25].

Researchers have reported that solar roof ventilation has a better performance as compared to the Tromb wall, especially when the altitude of the sun is high [26,27], as is displayed in Fig. 4.

3 Review of natural cooling

A study of the various cooling arrangement for household purpose indicates that evaporative cooling has superior performance as compared to the existing system [28], as is exhibited in Fig. 5. At present, two types of evaporative cooling, namely, direct and indirect cooling, are adopted.

In this cooling system, the sensible heat gets converted into latent heat and the temperature of the moving air gets decreased, as shown in Fig. 6. The proper high quality desiccant is applied to improve the system efficiency [30–32].

A standard photograph of indirect evaporative cooling is demonstrated in Fig. 7. In this system, heat transfer takes place by the two different airflow streams.

A study of the application of evaporative cooling in buildings has been conducted by Wanphen and Nagano. The siliceous shale keeps the surface moisture in the vapor adsorption system. By this, system produces the best performance.

4 Recent development of heating and cooling in buildings

At present, due to the shortage of energy and its

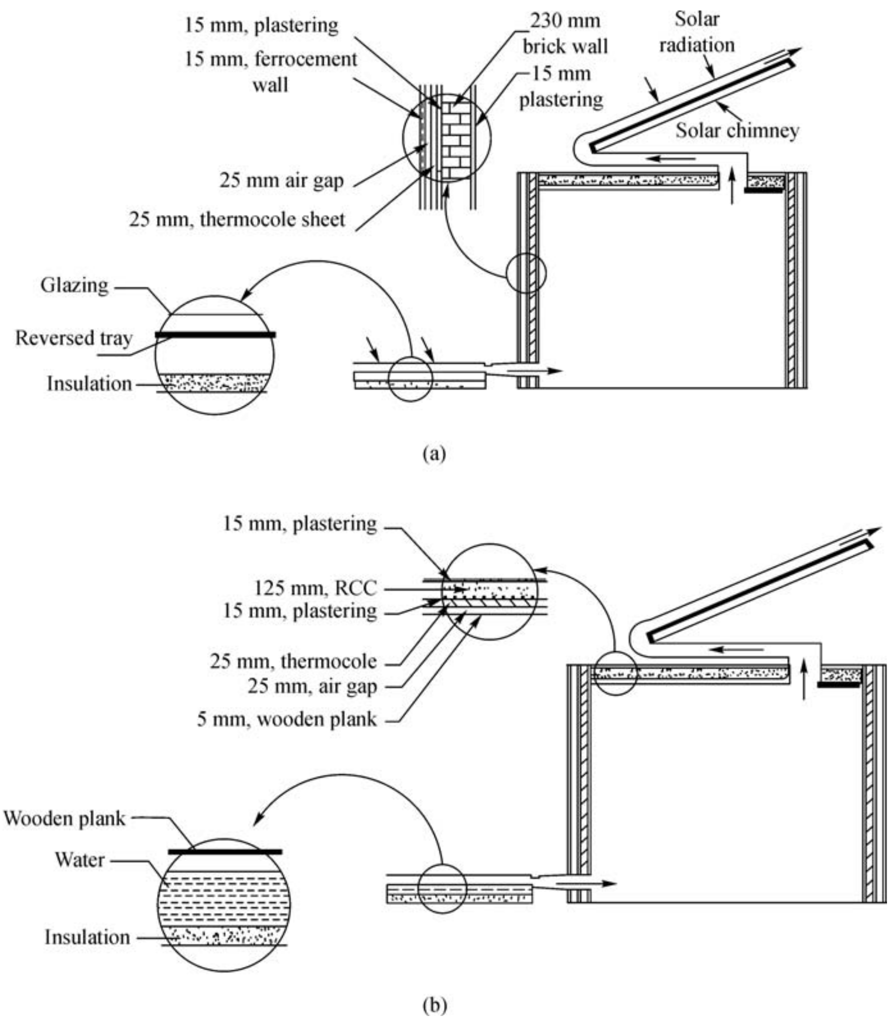

Fig. 2 A solar heating and cooling system with a chimney
(a) Winter; (b) summer [22]

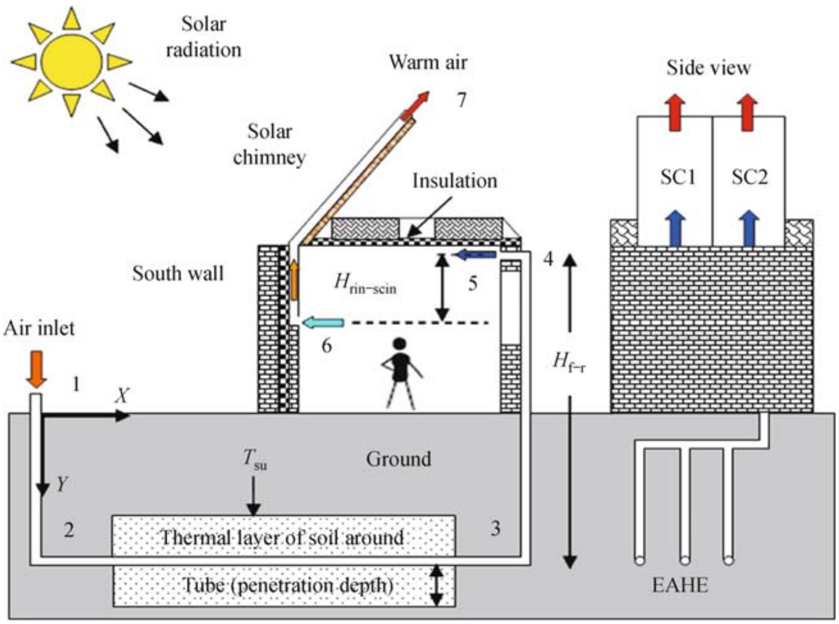

Fig. 3 An integrated EAHE and solar chimney [23]

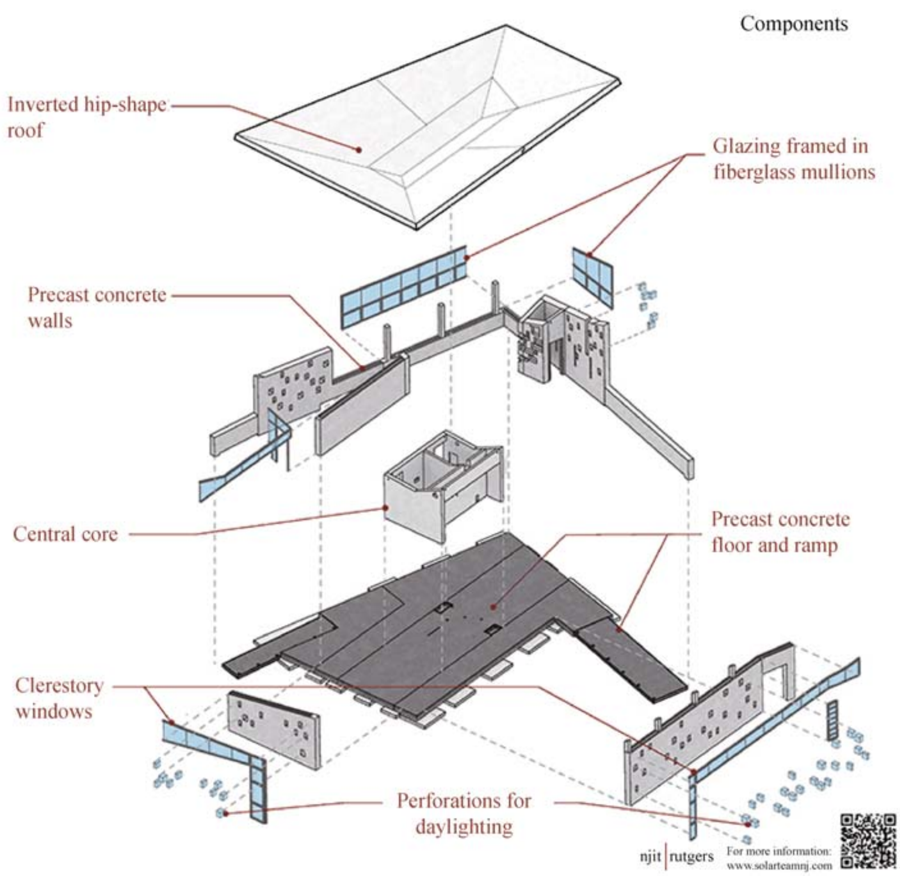

Fig. 4 Schematic diagram of solar roof (solarteamnewjersey.com)

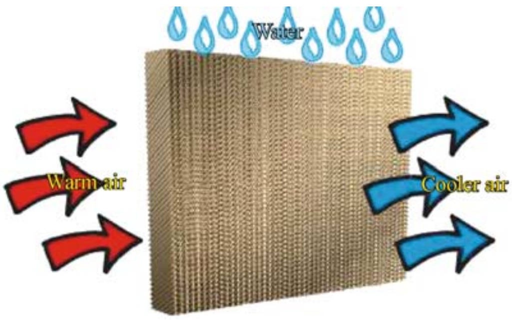

Fig. 5 Evaporative cooling [29]

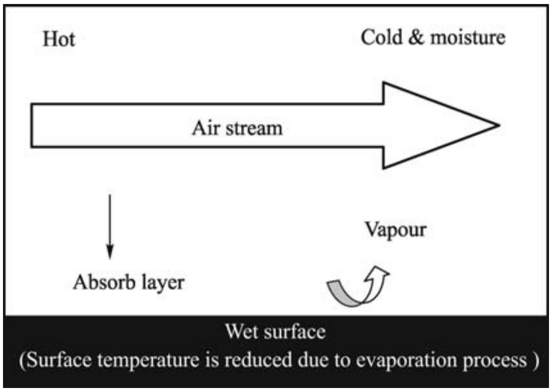

Fig. 6 Direct evaporative cooling [30]

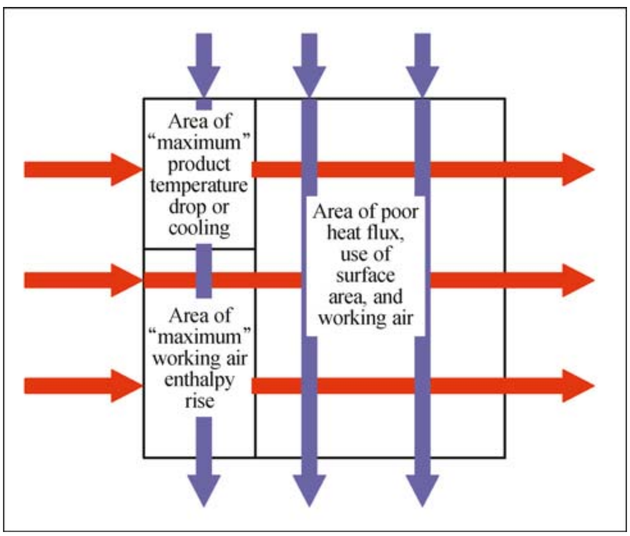

Fig. 7 Indirect evaporative cooling (rexresearch.com)

conservation in the western Indian Himayan state such as Himachal Pradesh, the government has enforced a rule for the new construction of the government buildings, as presented in Fig. 8 [33]. All newly constructed buildings should be passive solar ones in that region. Since Himachal Pradesh, India come in that locality, this rule has been applied in that region, too. Such a building saves considerable amount of the grid connected electricity. In this paper, a study has been conducted of one of the passive buildings in Mandi, Himachal Pradesh, India. Such a building has modification in floor plans, arrangement of windows, shading, provision for hot air by solar energy, cross ventilation, and other important modification in the structure which increase the indoor thermal comport. By such modification, the building utilizes maximum possible natural energy and minimizes the requirement of grid-connected electricity. This comfort is being evaluated based on the standard suggested by ASHRAE Standard 55 protocol. The indoor data have been simulated by the e-Quest software. The result of the study reveals that by such modification as promised, the building requirement for grid-connected electricity has been considerably reduced.

Benhammou et al. have conducted a unique study of the cooling of the building in the hot region, as shown in Fig. 9 [34]. They applied the earth air heat exchanger along with a wind tower for natural cooling in the summer season in Algeria. They have developed the mathematical model for the proposed system to the proper analysis based on the observed experimental data. The model is applied to predict the inside air speed in the pipe.

The building sector is responsible for most of the energy and materials consumption today. Building systems, such as green roofs, can improve the energy efficiency of buildings, and in the meantime, they need to be more sustainable. This study focuses on the advantages in terms of energy consumption, a large green roof (without an insulating layer) as compared with a conventional flat roof (decision insulated) in the Mediterranean continental climate [35]. The schematic diagram of the system is presented in Fig. 10. In addition, in order to improve the stability of the system, the use of recycled rubber, instead of the traditional stone materials in the drainage material is also estimated. For this purpose, the power consumption in the cooling system, the thermal properties of the three identical pilot cabins, and the differences in the composition of the roof are evaluated during the summer period. The results show that the simple extensive green roof of 9 cm in thickness provides a reduction of 5% in the case of rubber crumb and 14% for pozzolans, in terms of power consumption than a conventional flat roof with an insulating layer of 3 cm polyurethane, even when only 20% of the surface is covered with the plant. In addition, small differences in thermal behavior are observed when replacing the volcanic gravel from recycled rubber crumbs as a drainage material.

The information about the performance and efficiency of the annual performance of construction and integrated solar energy systems for solar water heating systems and solar photovoltaic (PV) modules demonstrating near-zero energy solar house have been provided, which has been built on the campus of the Korean Institute for Energy Studies. The heating systems installed in the house are

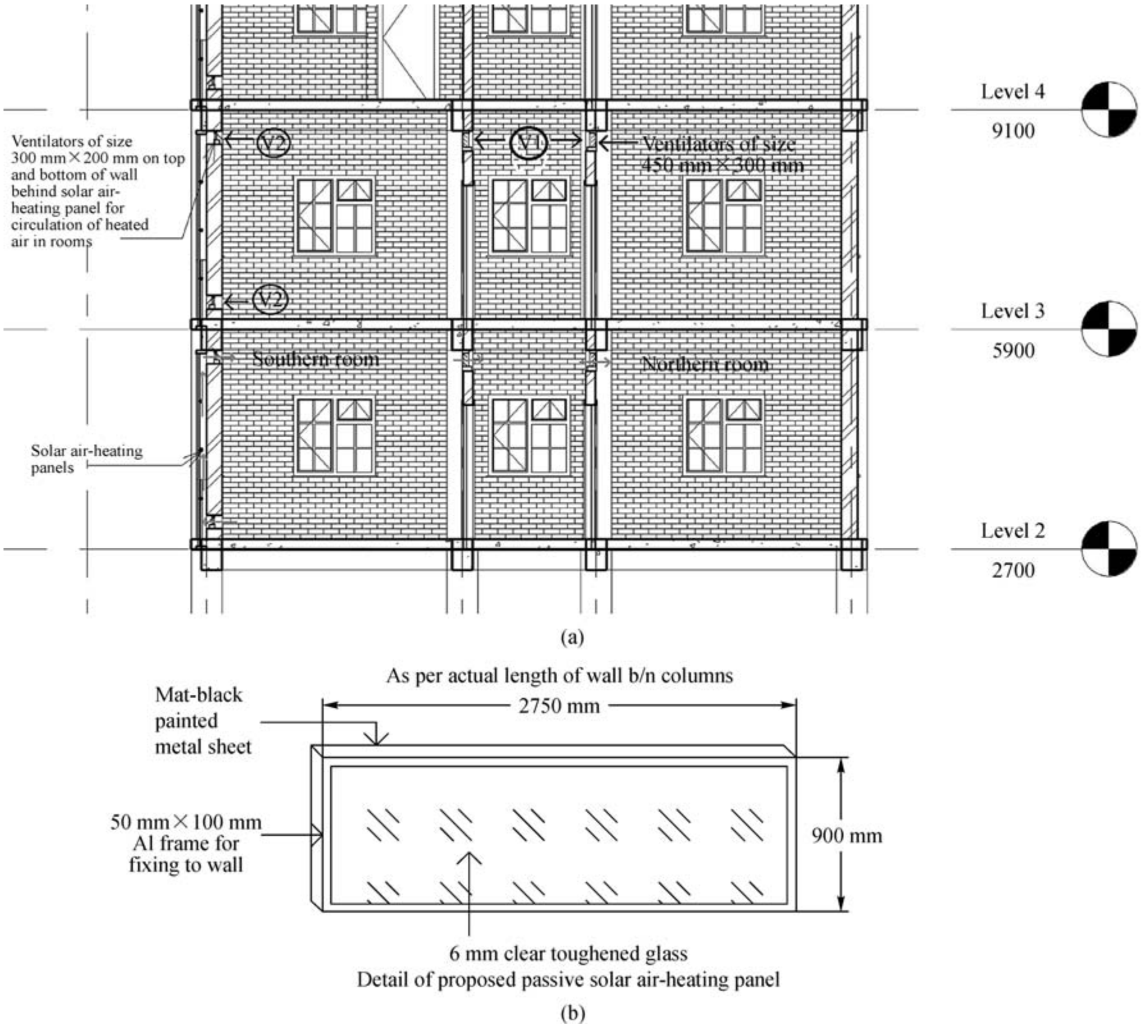

Fig. 8 Details of proposed passive solar air-heating panel
(a) Air circulation plan for the building; (b) air heating panel [33]

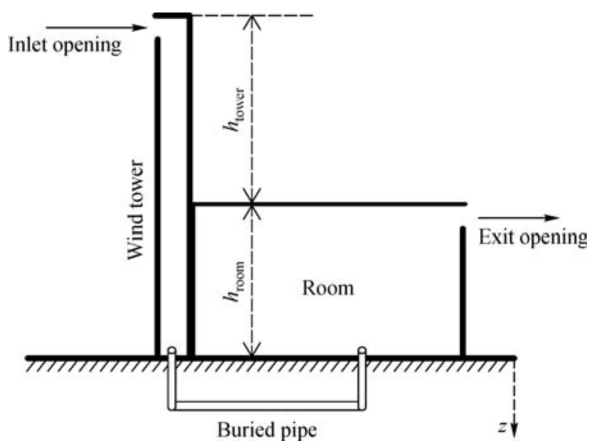

Fig. 9 Schematic diagram of the proposed system [34]

solar water heating systems with building-integrated solar collectors for water heating and space heating and a grounded heat pump for space cooling and heating of the premises [36]. Solar PV modules have been installed on the roof of the house. The effectiveness of these systems has been monitored by more than one year. The annual efficiency of the building integrated solar collectors and solar PV is 22.8% and 10.9%, respectively. The total annual solar fraction of the solar heating system is 69.7%, with an annual production of solar heat of 248 kWh/ m^2. This paper also focuses on the efficiency of the solar storage house based on a variety of special drainage of hot water from the tank. It is found that the heat loss of the solar storage tank is strongly related to the functional needs of the solar thermal reservoir per unit volume. For example, when the hot water consumption has been reduced by half in September, the heat loss increases to more than 70%, which otherwise would have been around 30%.

At present in the United States, about 41% of the total energy is being utilized for the fulfillment of the building

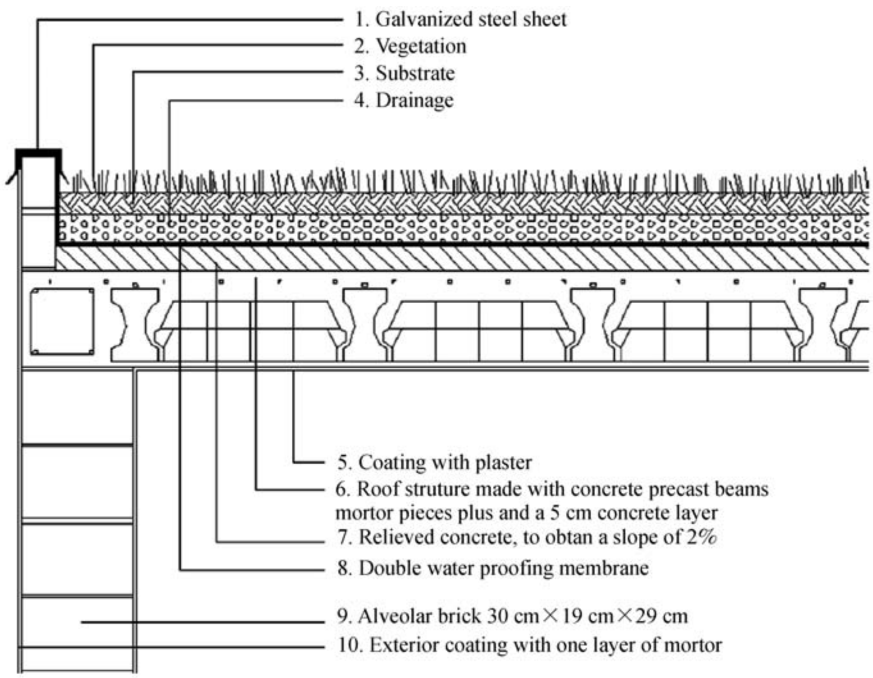

Fig. 10 Schematic diagram of the green roofs cubicles for the building [35]

energy demand. Hence, there is a great emphasis to minimize the energy consumption in the building sector. These solar based methodologies, namely photovoltaic, water heaters, and transparent solar air collectors (TSAC), have been applied to save energy in the building [37], as shown in Fig. 11. The transparent solar air collector is an innovative energy saving conception which uses existing ventilation system for air heating. It is 60% to 80% efficient and has a payback time of only 2–8 years. This concept is very much applicable for cool weather regions.

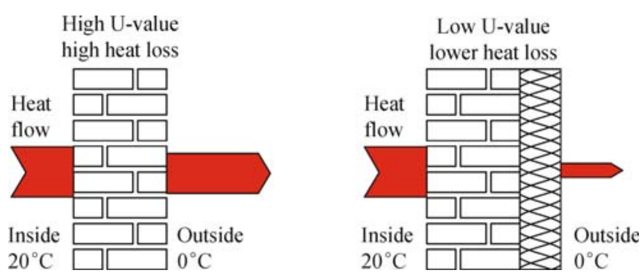

Fig. 11 Schematic diagram of wall and wall along with transparent solar air collector [37]

5 Conclusions

There are many active and passive solar designs for the proper comfort of the residents in buildings. In this system, proper provision for the heating and cooling is there. However, they have their own limitations. Therefore, there is a need for active solar innovations which is not only environomical but simple in operation and low in maintenance. It is observed that solar passive buildings, especially those in remote places, do not provide enough comfort. Hence, research should be conducted in this field to provide adequate comfort which is to be cost and environmental effective.

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