Report

Renovation Design of Architecture in Taiyuan City, China--Trombe Wall as a Passive Solar Heating Design Application

Abstract

Building energy consumption has been a significant problem in global energy consumption. The energy consumed by indoor cooling and heating is the most substantial part of the building's energy consumption. As a passive solar heating technology, Trombe Wall helps reduce carbon emissions and improve building performance at low cost. This paper uses Trombe wall technology to renovate existing buildings in Taiyuan City and uses DesignBuilder to simulate the winter indoor temperature of the building before and after the renovation. The experimental results show that the proposed Trombe wall design is feasible in improving the thermal environment. Other passive design strategies need to be introduced to achieve the thermal comfort of residents.

Introduction

Energy consumption in buildings has become a major impact of global environmental problems and energy crises, particularly electricity (Wang et al. 2019). In cold areas, especially where cold weather lasts longer, building heating and ventilation are a significant way to meet the thermal comfort indoor environment (Wang et al. 2019). However, in the process of building heating, passive design measures can effectively save the energy consumption of building heating, to achieve the goal of making energy saving. This paper will take residential buildings as an example, analysis of the construction of passive solar heating design in a cold and arid climate.

Passive design strategy

Passive design means that the house will use natural air to maintain a comfortable indoor temperature for the occupants. At present, there are many kinds of passive design can achieve building energy saving. According to Saadatian et al. (2012), the Trombe wall is a highly flexible wall that can be configured through the needs of the user and the different climates and seasons. It is mainly through solar energy to provide thermal comfort. Trombe walls store energy during peak periods of use and produce energy when the occupants need it (ibid).

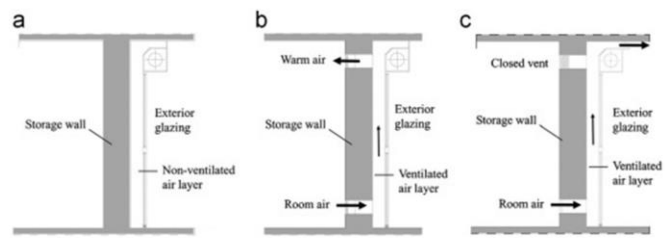

Fig.1 Various configurations of a solar wall: (a) without ventilation; (b) winter mode with air thermo-circulation; (c) summer mode with cross ventilation (Saadatian 2012).

Climate describes

Shanxi Taiyuan is located in northern China and is a typical winter cold and dry climate. According to the Koeppen-Geiger climate classification (2006), the weather in Taiyuan is BSk, which is arid, steppe, and cold arid. Therefore, the study will use meteorological data from Taiyuan.

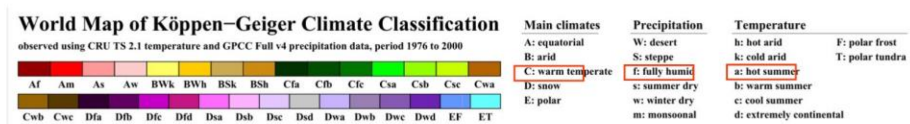

Fig.2 Shows Koeppen Geiger Climate Classification (Source: http://koeppen-geiger.vu-wien.ac.at/present.htm)

Taiyuan City belongs to the continental monsoon climate; the climate is distinct all year round, the temperature difference between morning and evening is massive in spring, the summer is hot and rainy, the autumn temperature drops faster, the winter is cold (Liu 2016).

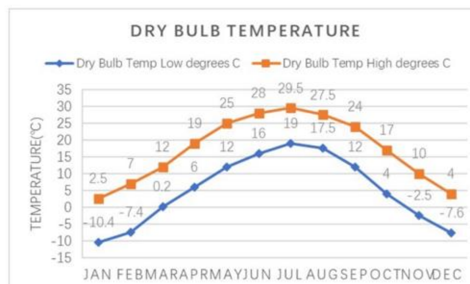

Fig. 3 Dry Bulb Temperature (Data from Energy plus)

When Taiyuan is the driest and hottest in June, the average maximum temperature can reach 29.5 degrees, and the minimum temperature is 19 degrees. Taiyuan's coldest season is in January, with an average maximum temperature of 2.5 degrees and a minimum of minus 10.4 degrees.

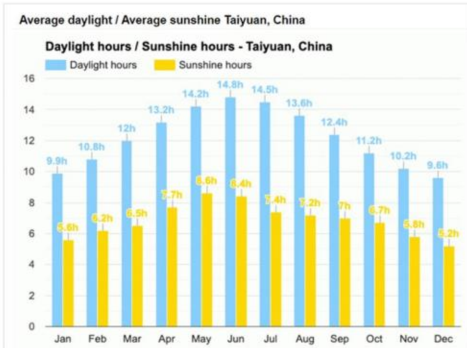

Fig.4 Average Daylight Hours and Sunshine Hours (Source:https://www.weather-atlas.com/en/china/taiyuan-climate)

In terms of sunshine, from the average sun in Taiyuan, it can be seen that Taiyuan City has plenty of light time in a year, with a minimum of 5.2 hours of sunshine in winter and the longest light time in summer, 8.6 hours in May.

Building describe

The residence is a 120 m2 single-story building with reinforced concrete structures. The exterior wall of the building is made up of 215mm medium density aggregate blocks wall with U-vale is 0.16 W/(㎡·K) (Thomas Armstrong 2015), the thermal capacity of the block is 1000J/kg/K (Lignacite 2019), and double glazing with U-vale is 2.0 W/(㎡·K). The block is dark in colour and will be of great help in absorbing solar heat in the future. Besides, this polymer block consists of 90 recycled raw materials and is the most environmentally friendly and sustainable material (Thomas Armstrong, 2015).maximum temperature of 2.5 degrees and a minimum of minus 10.4 degrees.

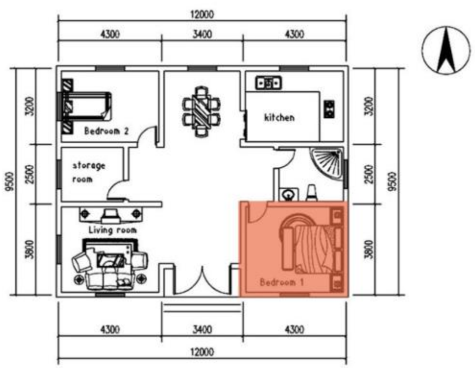

Fig.5 The building plan

Literature

A Trombe wall is a system that indirectly heats circulating air by absorbing solar radiation, and stores heat energy in a wall to heat the room indoors (wang et al. 2019). The wall is merged with the enclosed space, and an external glass layer covers it with an air pipe in the middle. Huge heat absorbs energy from the outside glass, and the stored energy is passively released into the air by natural convection to increase air temperature (Abdeen et al. 2019), heat it in winter, or cause airflow in summer to cool down (Gan 1998).

It stores solar energy during the day and heats the occupants at night to heat the indoor temperature (Dabaieh and Elbably 2015).This means that the use of passive Trombe walls requires adequate lighting. Therefore, for best performance, this wall is usually placed on the south side of the building. This matches the orientation of the Bedroom1 facade of the renovation project selected for the study. In addition, Taiyuan's average annual lighting time is very long, which will help the Trombe wall to make full use of solar energy.

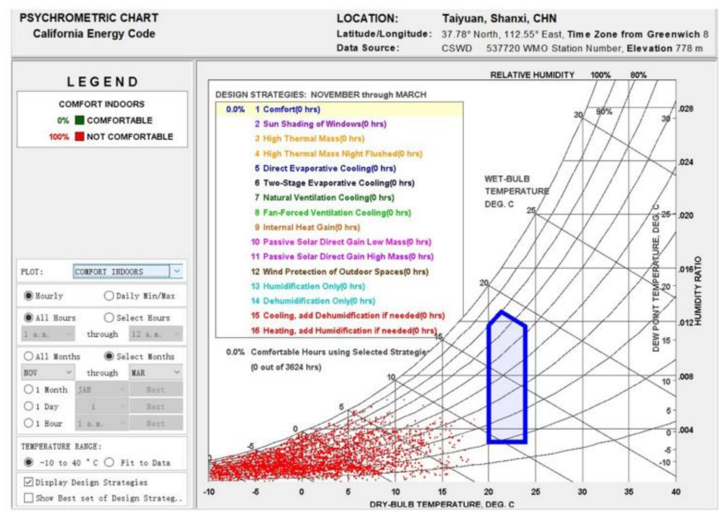

Fig.6 Bioclimate chart of the winter temperature in Taiyuan (November to March)

It is worth noting that the winter bioclimate chart (Fig.6) shows that there is no time in the comfort zone, and providing heat is necessary to improve winter comfort. As a result, the Trombe wall is used to generate sufficient energy after absorbing about 6 hours of sunlight during the day and releasing stored heat at night, providing a comfortable thermal environment for the occupants.

Methodology

The study will use the DesignBuilder software to renovate Beedroom1 using parameter simulation models. First, simulate the thermal performance of the original room, then use the retrofit design of the Trombe wall to affect the test winter room temperature. Compare the indoor temperature in winter in two cases.

Implementation of the methodology

The classic Trombe wall consists of four main parts: glass, air passage, heat storage wall, and vent. The wall surface is usually coated with black paint because the dark wall faces more solar gain (Saadatian et al. 2012).

Sunlight creates a greenhouse effect through the glass in the air passages formed between the walls, which form a density difference between heating and cold air in the room, creating a heating cycle of space (Wang et al. 2019). The occupants can control the two vents under the heat storage wall through a panel, and the vents are opened or closed according to different weather conditions (Fig.7).

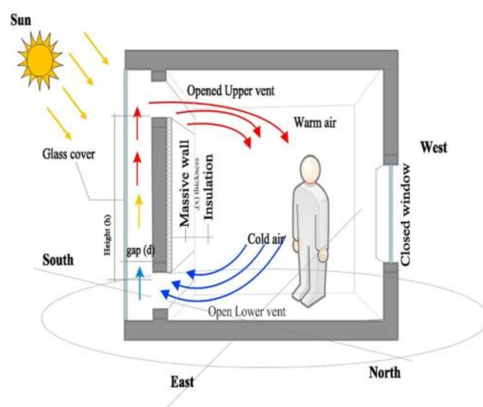

Fig. 7 Classic Trombe Wall Physics Map (Abdeen et al. 2019)

According to Abdeen et al. (2019), the best performance of the Trombe massive wall height is 1.7m, and the enormous wall thickness is 0.3m, the air passage depth is 0.22m. This data model increases indoor thermal comfort by 38.19%. Therefore, this data is used to model in DesignBuilder and replace the original building south facade. The new model of bedroom1 is shown in Figure 8.

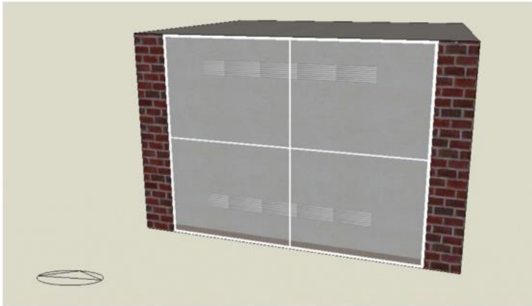

Fig.8 The new model of Bedroom1 (DesignBuilder).

Table 1 and table 2 show the thermal properties of the Trombe wall materials and the parameters of inputs, respectively.

Table 1. Thermal properties of Trombe wall

Material	Density (kg/m3)	Thermal conductivity (W/m2K)	Specific heat (J/kg)	Thermal resistance (m2K/W)
Trombe wall	1700	1.65	940	0.67

Table 2. The parameters of inputs

Parameters	Thickness (mm)	Massive height (m)	U-value (W/(m2·K))	Color	Total solar transmission
Trombe wall	300	1.7	1.075	Dark	-
Double glass	3 (13mm window gas)	2.8	1.514	Clear	0.647

It is worth noting that the U-value of the Trombe wall is much higher than the U-value of the original external insulated fence, which may seem like a set of unreliable data. However, since the Trombe wall absorbs and stores a lot of heat during the day, it requires a lower heat resistance to the wall at night to provide heat for the room (Saadatian et al. 2012). Therefore, this U-value is acceptable to ensure thermal comfort in the room. Winter indoor temperatures, especially night-time temperatures, will be the result of the investigation. This can intuitively see if this passive design strategy can improve the performance of buildings.

Result

The Trombe wall was simulated for 6 days (i.e., from 15 February to 20 February). The results show that in passive design, the change in indoor temperature of buildings is influenced by the outside temperature. The design of the Trombe Wall can effectively improve the indoor temperature. The room temperature has grown significantly under the sun during the day. However, the indoor temperature at night did not improve significantly. Figures 9 and 10 show the hourly indoor temperature and night-time indoor temperatures.

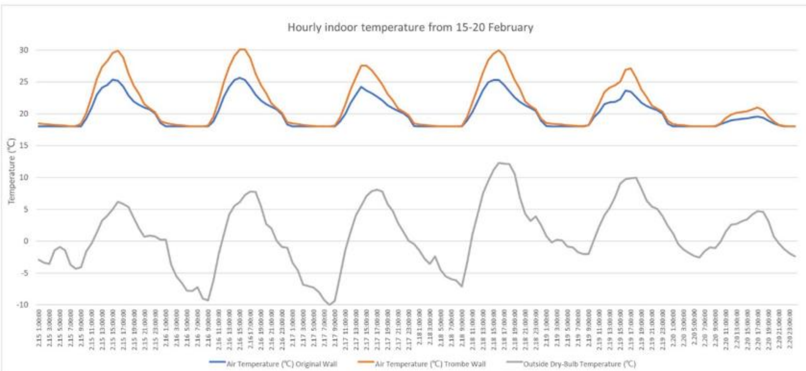

Fig. 9 Hourly indoor temperature from 15-20 February

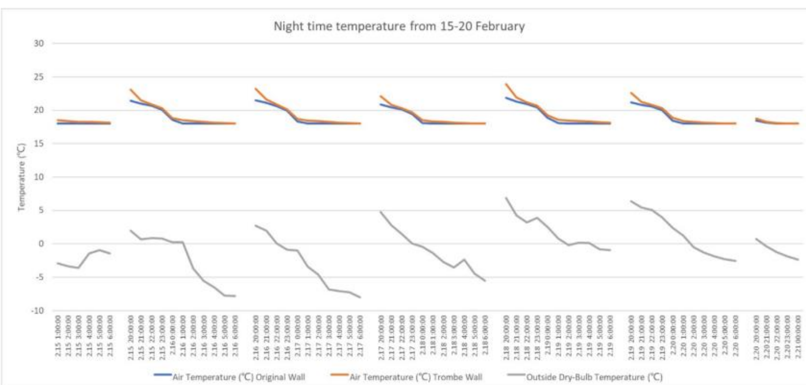

Fig. 10 Night-time temperature from 15-20 February

Discussion

In this study, the Trombe wall was used as a passive solar heating method in winter. The February in Taiyuan City, which there is a more extended period of sunshine time, was selected to be subjected for simulation monitoring, with an average of 6.2 hours of sunlight exposure (Figure 4). The simulation results from DesignBuilder are performed when the building is as fit as possible to run correctly. The input wall parameters are also a set of experimental data that can significantly improve the performance of buildings after a lot of literature research. The experimental results the structure locates on the south side of the bedroom, which is renovated by Trombe Wall. And the room temperature has improved significantly during the day; it does not achieve the expected results of this passive design strategy, which enhances the indoor temperature at night and meets the thermal comfort of the occupants. Thus, the Trombe wall as a winter passive solar heating method can help improve the heat environment of the building, but to achieve indoor residents of thermal comfort also need to adopt other design strategies. For example, using a passive phase change materials (PCM) latent heat storage system may be helpful.

Conclusion

In conclusion, renovating old buildings is an effective solution for China to save building energy and reduce carbon emissions. Trombe wall technology with an energy-saving effect can effectively improve building performance and adjust the indoor temperature of buildings in winter. A bedroom was selected in Taiyuan City, China, to conduct an experimental study of the thermal environment of the low-cost Trombe wall in winter. Full consideration is given to the thickness, size, colour, wall material, glass specifications, and wall orientation that affect the thermal properties of the Trombe wall. Combined with local climate data from Taiyuan City, February was selected as the time target for winter monitoring. The experimental results show that the passive solar design strategy can help improve the thermal environment of buildings, but it does not meet the comfort of occupants. Therefore, there is a need for a further study of the passive change materials (PCM) latent heat storage system.

Reference

Abdeen, A. et al. 2019. Experimental, analytical, and numerical investigation into the feasibility of integrating a passive Trombe wall into a single room. Applied Thermal Engineering154, pp:751-768. Doi: https://-doi.org/10.1016/j.applthermaleng.2019.03.090

Albayyaa, H. et al. 2019. Energy conservation in residential buildings by incorporating Passive Solar and Energy Efficiency Design Strategies and higher thermal mass. Energy and Buildings 182, pp:205-213.

Dabaieh, M. and Elbably, A. 2015. Ventilated Trombe wall as a passive solar heating and cooling retrofitting approach; a low-tech design for off-grid settlements in semi-arid climates. Solar Energy122., pp:820-833. Doi: 10.1016/j.solener.2015.10.005

Gan, G. H. 1998. A parametric study of Trombe walls for passive cooling of buildings. Energy and Buildings27(1), pp: 37-43. Doi: https://doi.org/10.1016/S0378-7788(97)00024-8

Koeppen-Geiger Climate Classification. 2006. Koeppen-Geiger Climate Classification

Lignacite. 2019. Concrete blocks lignacite fair-face, paint grade and standard.

Liu, J. 2016. Weather and climate features in Taiyuan City, Shanxi Province. Global Human Geography4, pp: 236-236. Doi: https://doi.org/10.3969/j.issn.2095-0446.2016.04.188.

Saadatian, O. et al. 2012. Trombe walls: A review of opportunities and challenges in research and development. Renewable and Sustainable Energy Reviews16(8), pp:6340-6351. Doi: 10.1016/j.rser.2012.06.032

Thomas Armstrong. 2015. Concrete blocks product and technical guide. Thomas Armstrong (holdings): Workington Road, Flimby, Maryport, Cumbria.

Wang, D. J. e al. 2019. Classification, experimental assessment, modelling methods and evaluation metrics of Trombe walls. Renewable and Sustainable Energy Reviews124. Doi: https://doi.org/10.1016/j.rser.2020.109772

Wang, X. L. et al. 2019. Collaborative optimization between passive design measures and active heating systems for building heating in Qinghai-Tibet plateau of China. Renewable Energy147(1), pp:683-694.

Wang, W. S. et al. 2019. Numerical investigation on the impact of an on-top sunspace passive heating approach for typical rural buildings in northern China. Solar Energy186, pp:300-310.