Measuring Study on Energy Saving Performance of the Trombe Wall in School Building

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Abstract. The thermal engineering and energy saving performance of the Trombe wall of a laboratory building in a middle school of Lanzhou region in northwest China were measured and investigated. The results show that during the normal using period in winter 10 years after the building was built, the daily convection heat supply of single group vents is 6.89 kW, the daily average thermal efficiency of the Trombe wall is 18.4 %. In addition, in the process of using the building, it needs to notice that the ventilated channel must be maintained clean and unhindered status, the vents devices must be repaired periodically in order to ensure good opening and closing function, and the vents should be avoided blocking and the ventilation heating mechanism of the Trombe wall should be avoided destroying in later renovation or decoration of the building.

Keywords. Trombe wall, thermal efficiency, vent, school building.

1. Introduction
Firstly put forward by Felix. Trombe [1-2], the director of Odeillo Solar Institute, France in 1973, the Trombe wall is a kind of building external wall construction system with heat storage function. Later, it was widely used and developed in passive solar buildings. The Trombe wall system is an important type of indirect heating mode passive solar buildings, whose advantages are that the construction technology is of moderate complexity and thermal efficiency is higher. From the point of view of the mechanism and effect of thermal utilization in winter, many studies at home and abroad have been carried out to study the heat transfer characteristics of upper and lower air vents under open and closed conditions by means of experiments and numerical simulation.

Wang et al. [3-4] used Fortran77 language to compile a simulation calculation program PSHDC for the prediction and design of dynamic thermal performance of the Trombe collector wall. Chen et al. [5] carried out an experimental study on a passive solar laboratory in Dalian city in China. Quantitative analysis about the restraining heat dissipation effect of rolling curtain on the Trombe collector wall in winter night was made, and the analysis method for the reasonable location of installing the rolling curtain was put forward. Yang et al. [6] used CFD commercial software package Fluent to simulate the improved Trombe collector wall system, study its dynamic thermal characteristics, analyze the sensitivity of wall material, wall height, air interlayer thickness and other influencing factors, and give the suitable wall material and structure form. Briga-Sá et al. [7] studied the characteristic of the thermal parameters of the Trombe collector wall under the different ventilation vent opening and closing conditions by theoretical and experimental methods. Wang et al. [8] tested and studied the heating performance of the single-storey small house with the Trombe wall newly built as
demonstration project in Gangcha County, Qinghai Province, China. Chen et al. [9] made use of numerical and experimental methods to study the dynamic heat collection and supply characteristics of the Trombe collector wall with different thermal insulation structures. He et al. [10-12] conducted a comprehensive experimental and numerical study on the heat transfer characteristics of the Trombe collector wall with venetian blind structure. Rabani et al. [13-14] proposed a new type of Trombe wall with chimney, and has carried out experimental and numerical analysis. Duan et al. [15] studied the effects of different types of collector plate, collector hood and heat transfer mode on the thermal performance of the Trombe collector wall by experimental method.

Above facts indicate that the current research on the Trombe collector wall is mainly focused on theoretical and numerical simulation, experimental tests in laboratory. There is lack of testing and evaluating on practical thermal performance, heating efficiency and use management of large-scale buildings, especially public buildings in the process of use. Therefore, in this paper, tests of three consecutive days of a passive solar building with the Trombe wall in the fourth Middle School of Yuzhong County, Lanzhou City, Gansu Province, China, were carried out in the heating period of winter, post-use evaluation analysis on the Trombe wall of the passive solar building was also carried out, and the optimization measures were put forward. These results provide the basic data and design management reference for the promotion of the Trombe collector wall in public buildings in the cold area of northwest China.

2. Test Survey

2.1. Local Climatic Conditions
Gongjing Town, Yuzhong County, Lanzhou City, China is located on the Loess Plateau and has a dry climate. It is a typical arid and semi-arid mountain area with an elevation of 2480 m. The temperature difference between day and night is large, the annual precipitation is 250 ~ 300 mm, the mean daily minimum temperature in January is -13.2 °C, the annual total radiation can reach 5220 MJ/m². The ratio of sunny days in winter is high and the total solar radiation level is very high before and after the coldest month. The total solar radiation intensity can reach 1000 w/m² according to the measured results from December 25 to 27 at noon before and after 3 hours in the southward vertical plane. Because the latitude of this place is high and the solar height angle is small in winter, the total solar radiation intensity in the south vertical plane is much higher than that in the horizontal plane, so it is more favorable for the southern Trombe collector wall to exert its efficiency.

2.2. Test Object
The fourth middle school of Yuzhong County, Lanzhou City, Gansu Province, China is located in north mountain area of Gongjing Town, Yuzhong County, Lanzhou City, longitude 104.386 ° east, latitude 36.064 ° north. In 2004, the laboratory building was built with a three-story brick-concrete structure. The Trombe collector wall was adopted in the southward exterior building wall. The whole testing process is in the normal teaching period of the school. In order to reduce test interference, a standard classroom used for the physical laboratory located on the second floor of the laboratory building with non class state was selected as the test room, and the whole building was not heated during the test process. The plane of the test room and the section of the Trombe collector wall and the measuring point layout are shown in figure 1 and figure 2. The size of air vent is a rectangle with a width of 250 mm and a high of 150 mm.
3. Experimental Test

3.1. Test time, Parameters and Instrument

The solar height angle at noon in the day of winter solstice is the minimum among all values of solar height angle at the same time point of annual any day. Therefore, under the same meteorological conditions, the maximum solar radiation can be obtained on the south vertical plane. Based on the above result, three consecutive days with sunny weather conditions after the Winter Solstice day, December 25-27, are chosen as testing period. In this period, the school is still in class and the buildings are in normal operation. The chosen testing period can better reflect the thermal heating characteristics and the actual use state of passive solar building with the Trombe collector wall in the normal winter. The measured parameters include the total solar radiation intensity, indoor and outdoor air temperature, air temperature and velocity at the vent of the collector wall, the surface temperature and heat flux intensity of the collector wall system. The total solar radiation intensity is measured by using the JTDL-4 four-channel solar radiation tester and the JTTS-01 total radiation meter of Beijing Century Jiantong Technology Co., Ltd. The sensitivity of the instrument is 9.85 μV/(W·m⁻²). Measurement of indoor and outdoor air temperature and air temperature of the vent in Trombe collector wall depends on using TPJ-20 temperature and humidity recorder. The air velocity at the vent of the collector wall is measured with ZRQF-J intelligent hot ball anemometer. JW-II type temperature and heat flux circuit detector is used to measure internal and external surface temperatures and heat flux intensity of the heat collecting wall, T-type copper-constantan thermocouple is adopted for temperature sensor, and JTC08A heat flux meter is adopted for heat flux sensor. The heat flux conversion coefficient C=23.26 (W·m⁻²)/mV.

3.2. Test Results and Analysis

3.2.1. Total Solar Radiation Intensity. The test station is set up in the school playground without any shielding. The total solar radiation intensity in the horizontal plane is measured by one total radiation meter. Moreover, the total solar radiation intensity in the south vertical plane is measured by another total radiation meter. The test results are shown in figure 3. As shown in figure 3, the daily mean value of total solar radiation intensity in horizontal plane is 416 W/m², and the maximum value is 673 W/m². While the daily average value of total solar radiation intensity in the south vertical plane is 790 W/m², and the daily maximum value reaches to 1060 W/m², and the maximum value appears about 12:00 at noon. It can be seen that the total solar radiation intensity obtained from the south wall is obviously
higher than the total solar radiation intensity from horizontal plane because the solar height angle after
the Winter Solstice is close to the minimum value of the whole year, which provides a good external
heat source for the thermal utilization of passive solar buildings.

![Figure 3. Total solar radiation intensity on south vertical plane and horizontal plane.](image)

3.2.2. Indoor and Outdoor Air Temperature. The daily variation of indoor and outdoor air temperature
is shown in figure 4. The indoor temperature at night was stable at about 10.2 °C, gradually increased
after sunrise, reached the maximum value of 17.9 ºC at noon 12:00, then gradually decreased steadily,
and reached 11 ºC at midnight 0:00. The outdoor temperature has steadily maintained -11 ~ -9 ºC at
midnight 0:00 to 7:00 a.m., and gradually increased rapidly after sunrise at about 8 °C from 12: 00 to
15:00. The maximum value reached 8.6 ºC at 13:00 p.m., and decreased rapidly after 15:00 to -9 ºC at
23:00. It can be seen that the indoor and outdoor temperature difference between midnight and 7:00
a.m. can reach 20 ~ 21 ºC stably, and this stage can be regarded as a stable heat transfer stage. And
then from 9: 00 a.m. to 15:00 p.m., the indoor and outdoor temperature difference narrowed to about 9
ºC, and the increment of the indoor temperature was mainly due to the ventilation heating of the
Trombe collector wall and the solar radiation heating through the direct benefit window to the room.
After 15:00 p.m., the difference between indoor and outdoor temperature gradually increased to 20 ºC
at 22:00. The decrease of indoor temperature is slower than that of outdoor temperature because of the
delay effect of temperature transfer caused by heat storage and exothermic action of the Trombe
collecting wall.

![Figure 4. Indoor and outdoor air temperature.](image)

3.2.3. Air Temperature and Velocity at the Vent of the Trombe Collector Wall. The air temperature at
the upper vent and the lower vent on the collector wall is shown in figure 5. And the air velocity of the
upper vent is shown in figure 6. Figure 5 indicates that the air temperature of the upper vent reaches
the minimum 11.4 ºC in the whole day from 7:00 a.m. to 8:00 a.m., rises rapidly after 8:00 a.m.,
reaches the maximum value of 50.6 ºC at 14:00 in the afternoon, and then decreases gradually until
the end of 22:00 in the evening and later gradually stabilized at 12 ~ 14 °C. At the same time, the air temperature of the lower vent is maintained at 10 ~ 12 °C, reaches the lowest value 9.1 °C in the whole day at 8:00 a.m., increases slightly in the afternoon, maintains at about 12 ~ 13 °C, and reaches the full day maximum value of 13.2 °C at 20:00. From 23:00 to 8:00 a.m. of the next day, the air temperatures of the upper vent and the lower vent are stable, and the temperature difference between them is 1 ~ 2 °C. The average temperature difference in the time region between sunrise and sunset is 26.3 °C, and the maximum reaches 38.9 °C. The larger temperature difference between the upper vent and the lower vent provides a good condition for the formation of convection circulation heating in the air interlayer of the collector wall by hot compression.

**Figure 5.** Air temperature of upper and lower vents.  
**Figure 6.** Air velocity of upper vent.

The test time of ventilation wind speed at the vent is from 8:00 a.m. to 19:00 p.m., which is also an effective heating period for the vent opening. Because the law of the change of wind speed absolute value between the lower vent and the upper vent is very close, but the direction is opposite, figure 6 only provides the wind speed variation of the upper vent which the direction of the wind speed is that the hot gas flowing runs from the air interlayer to indoor room). As shown in figure 6, the wind velocity of the upper vent rises from 0.25 m/s at 8:00 a.m. to 0.62 m/s at 13:00 p.m., then stabilizes for about 2 hours, and then gradually decreases to the lowest value of 0.25 m/s from 18:00 to 19:00. The average wind speed is 0.45 m/s in whole test time from 8:00 a.m. to 19:00 p.m.

### 3.2.4. Inner and Outer Surface Temperature and Heat Flux Intensity of the Trombe Collector Wall System

The inner surface of the Trombe collector wall system is the inner surface of the solid brick wall, and the outer surface of the Trombe collector wall system is the outer surface of the double hollow glass. The diurnal temperature variation of both surfaces is shown in figure 7, and the variation of daily heat flux intensity on the inner surface is shown in figure 8. The direction of heat flux is outward from indoor to outdoor.

**Figure 7.** Temperature of inner and outer surface of the Trombe collector wall system.  
**Figure 8.** Heat flux intensity of inner surface of the Trombe collector wall system.
It can be seen from figure 7 that the range of diurnal change of the internal surface temperature of the collector wall system is relatively small, periodically changing from the lowest value 5 °C at 10:00 to the highest value 7.7 °C at 22:00 in the whole day. While the external surface temperature of the collector wall system has a large diurnal change of 50.9 °C due to the heating effect of solar radiation. The external surface temperature is stable at -10 °C from 0:00 to 8:00. This stage can be regarded as a stable heat transfer stage of the Trombe collector wall. After 8:00 o'clock, the maximum value is reached to 40.3 °C at 14:00 p.m., and then gradually decreases to -8 °C at 21:00 in the night. From figure 8, it can be seen that the direction of the heat flux of the inner surface of the collector wall system is always outward. From 0:00 at midnight to 7:00 a.m., the heat flux reached a stable equilibrium state, with an average value of 20.7 W/m². After sunrise the heat flux intensity decreases rapidly, and the mean value is 5.6 W/m² from 10:00 a.m. to 17:00 p.m., and then increases rapidly after 18:00, reaching 20.5 W/m² at 23:00 in the night.

4. Thermal Performance Analysis

4.1. Hourly Heat Supply

The heat supply to the indoor of the Trombe collector wall system is mainly composed of convection heat supply from the vent and heat dissipation from the collector wall to the room. Because the inner surface temperature of the collector wall is always lower than the indoor air temperature, the heat dissipation from the collector wall to the room is negative and is in the heat loss state, so it is ignored. Hourly convection heat supply \( q_0(\tau) \) can be determined by the following equation.

\[
q_0(\tau) = m(\tau)c_p(\tau)(T_i(\tau) - T_r(\tau))
\]

where, \( m(\tau) \) is mass flow through the upper and lower vents, can be written as:

\[
m(\tau) = \rho(\tau)v(\tau)A_u
\]

\( A_u \) is the area of the vent, and the area of the upper vent is taken in calculation. There are three groups of vents in a classroom, which every group of vent includes one upper vent and one lower vent. And the convection heat supply of one group of vents is shown in figure 9. It can be seen from figure 9 that the convection heat supply of a group of vents can be maintained at the level of 1000 W between 12:00 and 15:00 in the time range of about 3 ~ 4 hours.

![Figure 9. Indoor and outdoor air temperature.](image)

4.2. Daily Average Thermal Efficiency of the Collector Wall

The daily average thermal efficiency of the collector wall is the ratio of the effective heat supplied indoors on the collector wall in one day to the daily solar radiation obtained from the effective collection area of the same collector wall, which can be expressed as follows:
In equation (3), daily convection heat supply at air vent of collector wall $Q_0$ is calculated by the sum of hourly convection heat supply. $Q_0 = \sum q_0(t)$. Daily solar radiation from the effective collector area of a collector wall $Q_S$ is calculated by the sum of the hourly total solar radiation supply obtained from the effective collector area of the south Trombe collector wall. $Q_S = A \sum I_s(t)$. Here, effective heat collecting area of heat collecting wall $Q_0$ is the value of the transparent area of outer double hollow glass. The results of calculation are as follows. The daily convective heat supply $Q_0$ of a group of vents is 6.89 kW, the effective collecting area of a group of vents is 5.4 m², the daily solar radiation $Q_S$ is 37.34 kW, and the daily average thermal efficiency of the heat collector and storage wall reaches 18.4%.

5. Conclusions
As far as the overall life cycle of a building’s design and construction and using is concerned, the period after 10 years of construction is the good running-in stage. And the test and analysis of the solar energy building with the Trombe collector wall has a good applicability of post-building evaluation. The following conclusions and strategies can be obtained from the analysis of experimental tests and field investigation and evaluation.

(1) The average daily thermal efficiency of the Trombe collector wall in the laboratory building is 18.4%. Compared with the living building space, the public building space is larger, and the effective heat collection area of the heat-collecting wall is larger. For the space size of the ordinary classroom, the total heating area of three groups of air vents including the upper and the lower per group (the area of one vent is 0.25 m × 0.15 m, the total heating area is about 0.11 m²) in one classroom is relatively small in this case, which affects the improvement of the thermal efficiency. In addition, without changing the size of the vent, a movable fan can be installed at the vent to enhance the convection heat transfer capacity.

(2) In the use and management of the heat collecting wall system, pay attention to cleaning and hygiene in ventilation channel. Ensure smooth flow, good function of vent opening and closing device, regular maintenance and repair. Avoid blocking the vent and destroying the ventilation mechanism of the heat collecting and storage wall in the later stage of using or renovating the building.

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