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Technical note

The effect of Trombe wall on indoor humid climate in Dalian, China

B. Chen*, H.J. Chen, S.R. Meng, X. Chen, P. Sun, Y.H. Ding

Laboratory of Building Environment and New Energy Resource, School of Civil and Hydraulic Engineering, Dalian University of Technology, Dalian 116024, People's Republic of China

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Abstract

The paper clarified the effect of humidity adjustment of Trombe wall on indoor environment by the experimental comparison between a passive solar cell and a reference cell. Theoretical analysis on indoor humidity adjustment of Trombe wall in the passive solar cell is also performed based on steady moisture transfer theory. Simultaneously, the experiment proved that the passive solar cell could provide a relatively comfortable indoor environment.

Keywords: Moisture transfer; Passive heating and cooling; Moisture environment; Building energy saving

1. Introduction

In cold climate zones, the influence of moisture transfer on building envelop is very serious. It leads to many moisture-related problems with building energy performance, building maintenance, durability, human comfort and health. Traditional solution is to reinforce thermal insulation of exterior wall or ventilate frequently. Dewing on the building envelop has been prevented with the promulgation and enforcement of new building energy saving standards in the cold climate zones of China, but dewing on the external window still occurs frequently.

The ordinary walls are made of porous materials, much research has been carried out on moisture transfer of those walls. For example, using coupled transfer theory of heat

* Corresponding author. Tel.: +86 411 84706371.
E-mail address: chenbin8911@yahoo.com.cn (B. Chen).

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and moisture developed by A.B. Luikov, the influence of moisture transfer on thermal insulation behavior of building walls has been analyzed [1], experimental and theoretical researches on all kinds of walls have also been developed [2–9], as well as the moisture effects on conductive heat load [10]. Simplified method is commonly applied when using theoretical moisture transfer analysis as the result of complexity of the non-linear, hysteresis and non-isothermal characteristics of moisture transfer process. But in experimental research, it is very difficult to measure the local moisture content of porous wall, which bring hardness in carrying out accurate analysis. A method for the calculation of instant moisture distribution of porous material by measuring the instant temperature distribution is introduced in Ref. [11], but this method is developed under the assumptions of one-dimensional and single-phase condition.

In this paper, the authors clarified the effect of humidity adjustment of Trombe-wall on indoor environment by comparing transient variations of moisture content between a passive solar cell and a reference cell. Using measured inner surface temperature of exterior door/window of the two cells, whether and when dewing occurs was also examined.

2. Methodology

2.1. Experimental apparatus

The experimental cells were built in Dalian, China. Dalian is in the north semi-humid temperature district, which has abundant solar radiation round the year. The mean outdoor temperature in winter is -4.5 to -6.0 °C, and the lowest temperature may drop to about -21 °C, and the frost-free days ranges from 180 to 200 days.

The external view of the test cells is shown in Fig. 1. The test cells consist of a passive solar (PS) test cell and a reference cell. The dimension of the PS cell is $3.9\times3.9\times2.7$ m^3, and the south facade Trombe wall consists of a hollow glass covered with shading device inside the 100-mm thick air-gap and a 300-mm thick opaque wall. The opaque wall is made of ferroconcrete for heat storage and its external absorptive surface is painted with dark green lacquer. Two pairs of upper/lower rectangular vents, each 0.2 m$\times$0.15 m, are located in the integrated Trombe wall for convective heat transfer. The rest exterior walls of the test cells are made of 300-mm thick cinder block and 100-mm outside Styrofoam panel thermal insulation, 100-mm thick styrofoam panel is placed as the separating wall between the two cells. All the windows and doors are made of airtight frame and well-insulated hollow glass. The structure and physical parameters of the south facade walls are shown in Fig. 2.

2.2. Experimental procedure

The temperature and RH testing points are illustrated in Fig. 3. All of measured data were recorded every 10 min and saved in computer by a computerized data-logger device. The thermal recorder (RHLOG) also measured those data of the inner surface of the wall. The temperature and RH data of the two cell centers (see Fig. 3, EDPT/RHR and RDPT/RHE) and inner air-gap (see Fig. 3, EHAL/EHAR) were collected by Thermal Recorder

Fig. 1. South facade view of the test cells.

72S (TR-72S). Outdoor parameters (temperature, relative humidity and wind speed) were recorded every 10 min by WMR968 cable free weather station. The position and notations of the testing points are shown in Fig. 3, and all the testing points were set at the half height of the cell.

3. Results and analysis

3.1. Moisture content distribution in different walls

The experiment has been carried out from November 27, 2003, when the cells were just completed and the walls had high moisture. Fig. 4 shows the transient variation of the moisture content of the two cells in different weather conditions. It can be seen in Fig. 4(a), the moisture content in PS cell is higher than that in the reference cell on cloudy days but lower in sunny days, due to direct irradiation to the glazing accelerating evaporation of water in Tromble wall to the air-gap. After a period of time, the moisture content in PS cell is evidently lower than that in the reference cell (see Fig. 4(b) and (c)). It is shown in Fig. 4(b) and (c) that about from 0:00 to 10:00 the indoor moisture content is higher in sunny days than that in cloudy days, while after 15:00, the case turns to be reverse. The influence of weather condition on the moisture content of reference cell is decreasing (Fig. 4).

3.2. Dewing analysis of the inner surfaces

The windows and doors were closed mostly during the tests. The RH of the air-gap, outdoor/indoor environment are shown in Fig. 5. In Fig. 5, the RH in the reference cell

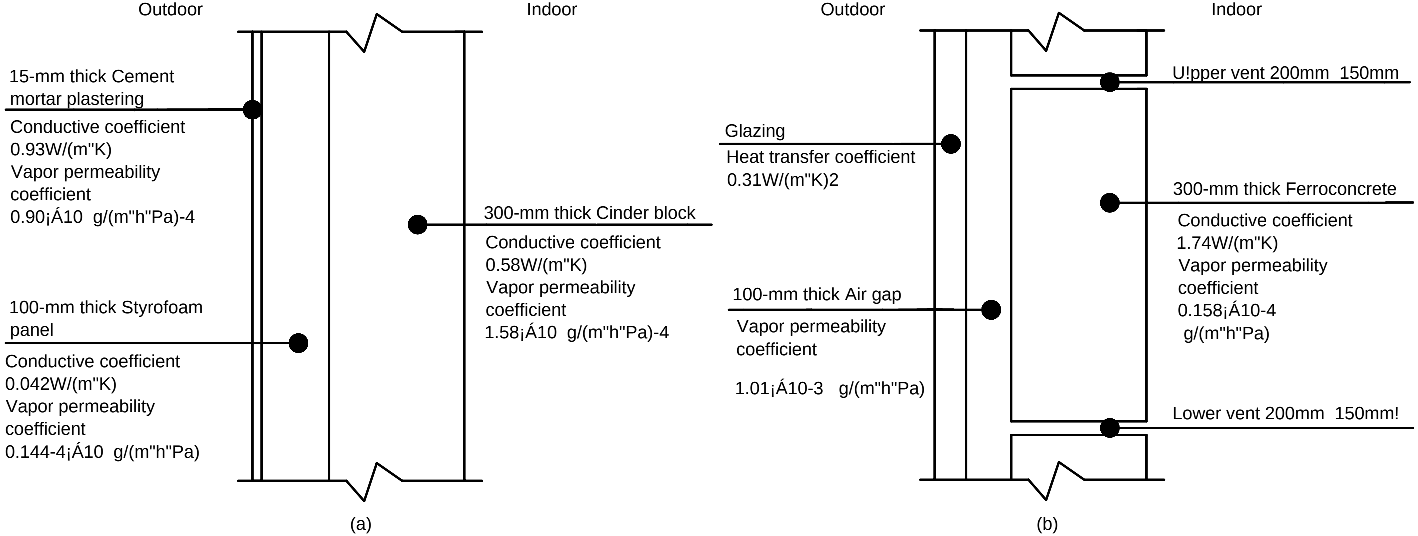


Fig. 2. Structure and physical parameters of the south facade walls. (a) Reference cell; (b) PS cell with Trombe wall.

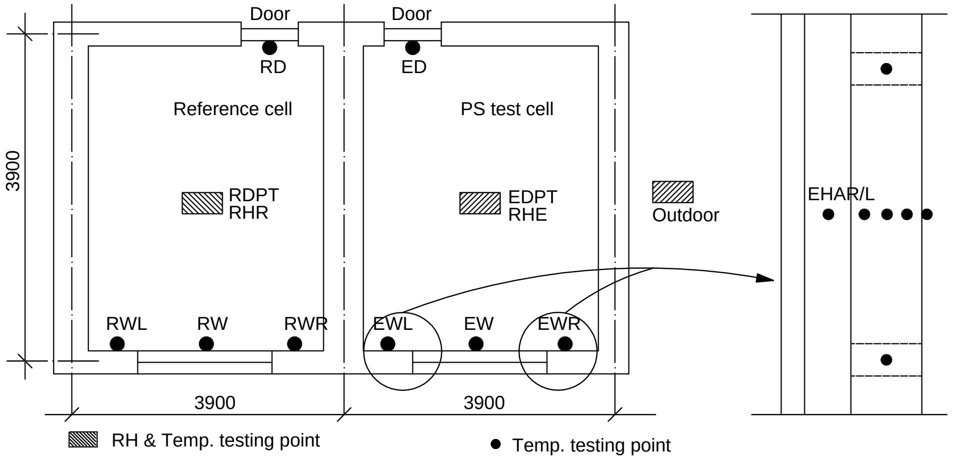
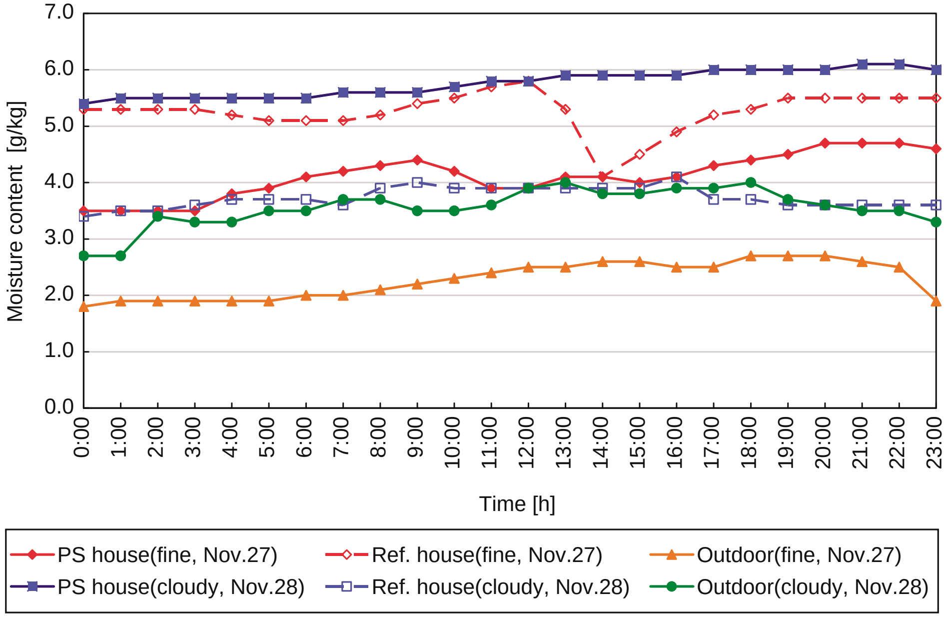


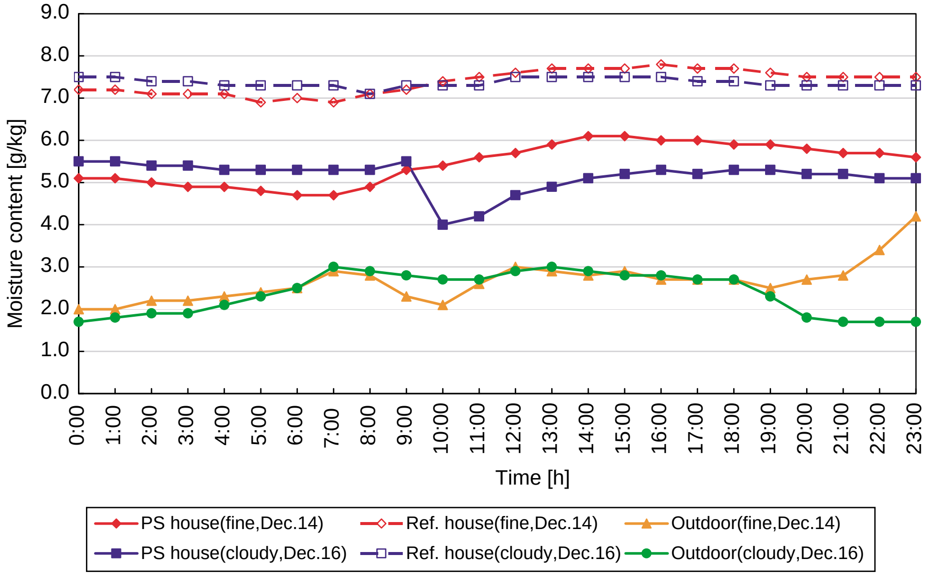
Fig. 3. Sketch map of RH and temperature testing points.

was up to 80% most of the time, even the lowest RH was above 60%, and nearly 20% higher than that in PS cell. Because of much solar thermal absorbed by air-gap, the RH in the air-gap was much lower than that of the indoor in PS cell. It made moisture in the walls just transfer to the air-gap, not to both sides of the walls. Due to this unique characteristic of moisture transfer, the humid climate in PS cell kept in appropriate comfortable level.

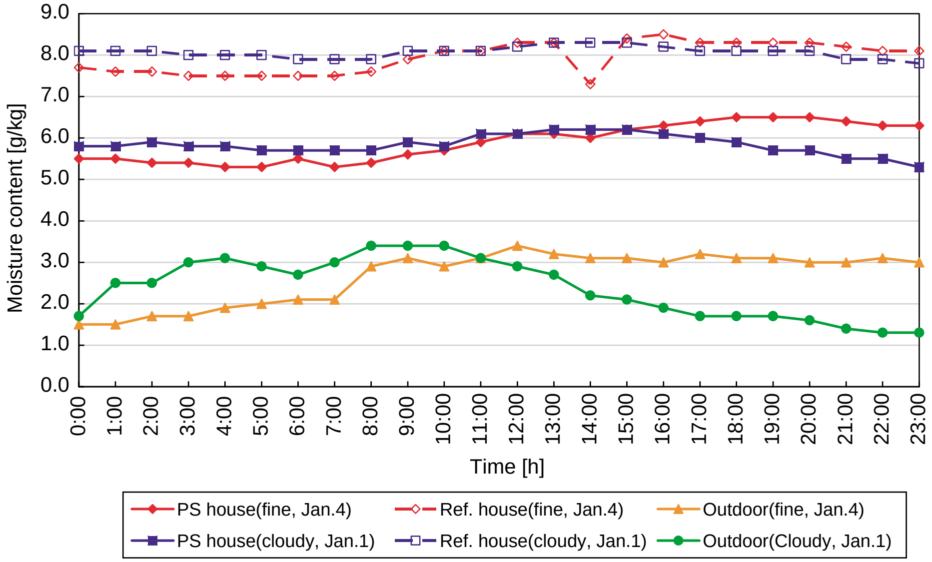


(a) November (The cell is just completed)

Fig. 4. Hourly variation of the indoor moisture content under different walls.



(b) December



(c) January

Fig. 4 (*continued*)

Fig. 6 shows the inner surface temperatures of the windows/doors and dew-point temperature of the indoor air in the two cells with respect to time.

As is shown in Fig. 6, the inner surface temperature of the south façade Trombe wall in the PS cell (EWL/EWR) is some 3–5 °C higher than it in the reference cell

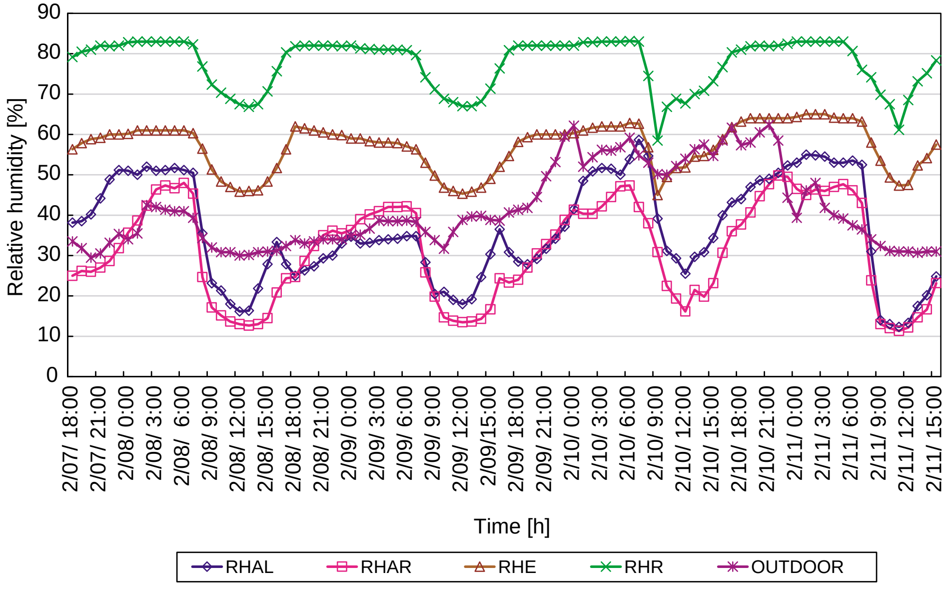


Fig. 5. RH variation in the air-gap and indoor/outdoor environment.

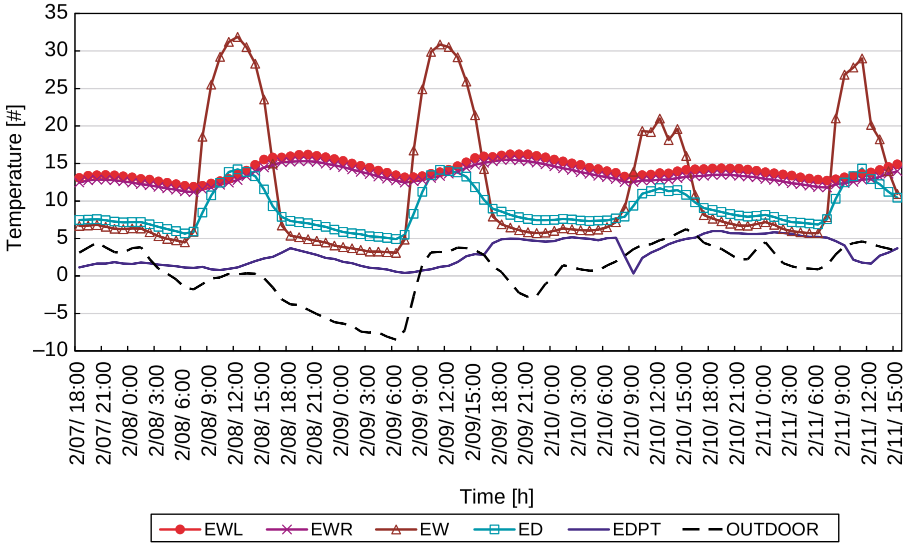
(RWR/RWL). The Trombe wall also causes the indoor air temperature of PS cell to fluctuate more than the reference cells. Although the temperature difference between two cells was small (about 1–1.5 °C), high RH in the reference cell made its dew-point temperature 3–5 °C higher. From 18:00 to 7:00 in the reference cell, the inner surface temperature of the door approached dew-point temperature and that of the window was lower than its dew-point temperature, so dew appeared. When the outdoor temperature is below −5 °C, dewing was very severe, whereas the PS cell kept dry throughout the whole experiment.

3.3. Vapor pressure distribution in the wall

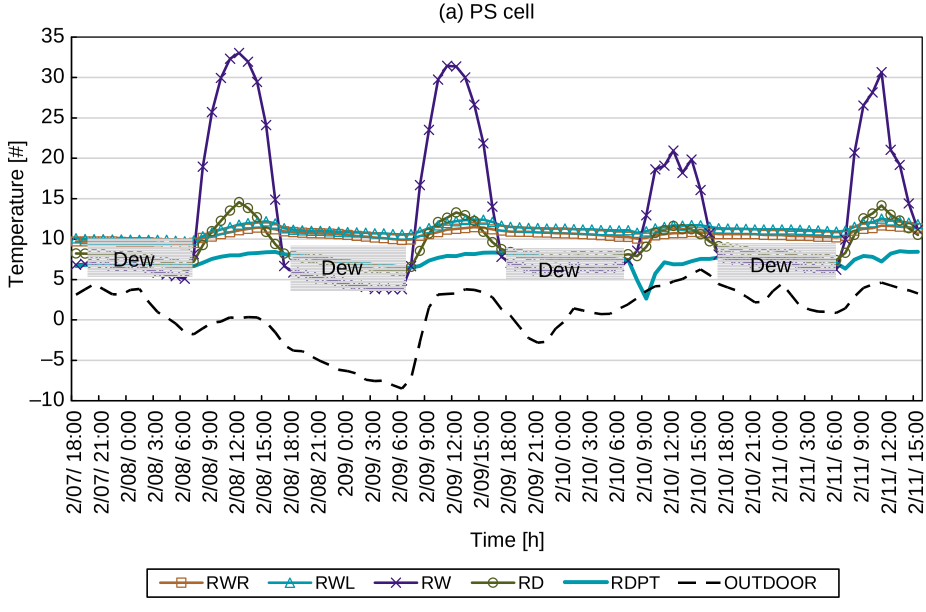
Moisture transfer in porous material is a complex problem containing vapor–liquid flow, phase change, coupled heat and moisture transfer. In order to simplify the analysis of moisture transfer, a method according to Ref. [12] is adopted to calculate the vapor pressure in the Trombe wall and the south façade wall of the reference cell. The procedure is as follows:

(1) Draw the saturated partial pressure of water vapor curves of the walls according to the tested surface and core temperatures of the walls (see Fig. 3).
(2) Determine the two sides' vapor pressure (P_i and P_e) according to the two sides' air temperature and RH. The vapor pressure of per layer (P_m) is calculated as follows:

$$P_m = P_i - \frac{\sum_{j=1}^{m-1} H_j}{H_0}(P_i - P_e), \quad m = 2, 3, 4, \ldots, n \tag{1}$$



(a) PS cell



(b) Reference cell

Fig. 6. Variation of inner surface temperature and dew-point temperature over 6 days.

where H_0 is the overall resistance of water vapor permeability of the composite wall, and equals to the sum of the resistance of the components. The parameters d_m and μ_m represent the thickness and water vapor permeability of the component, respectively. While the subscripts i and e stand for indoor and outdoor environment.

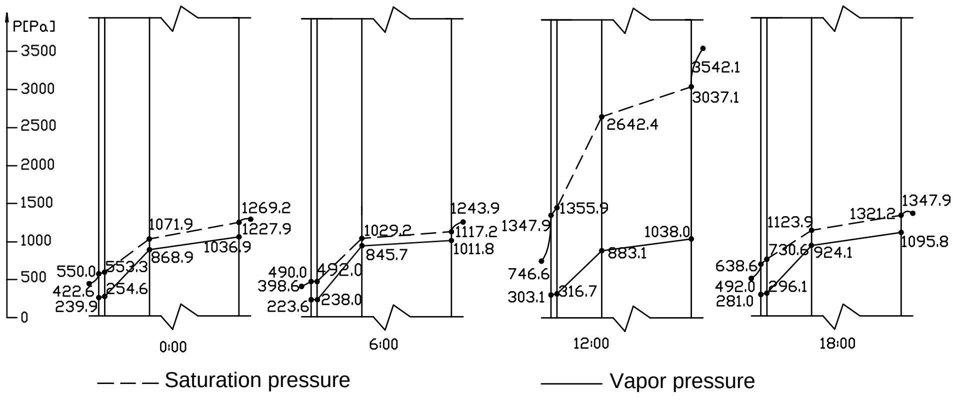


Fig. 7. Evaluation of condensation within the south facade wall of the reference cell at steady-state condition.

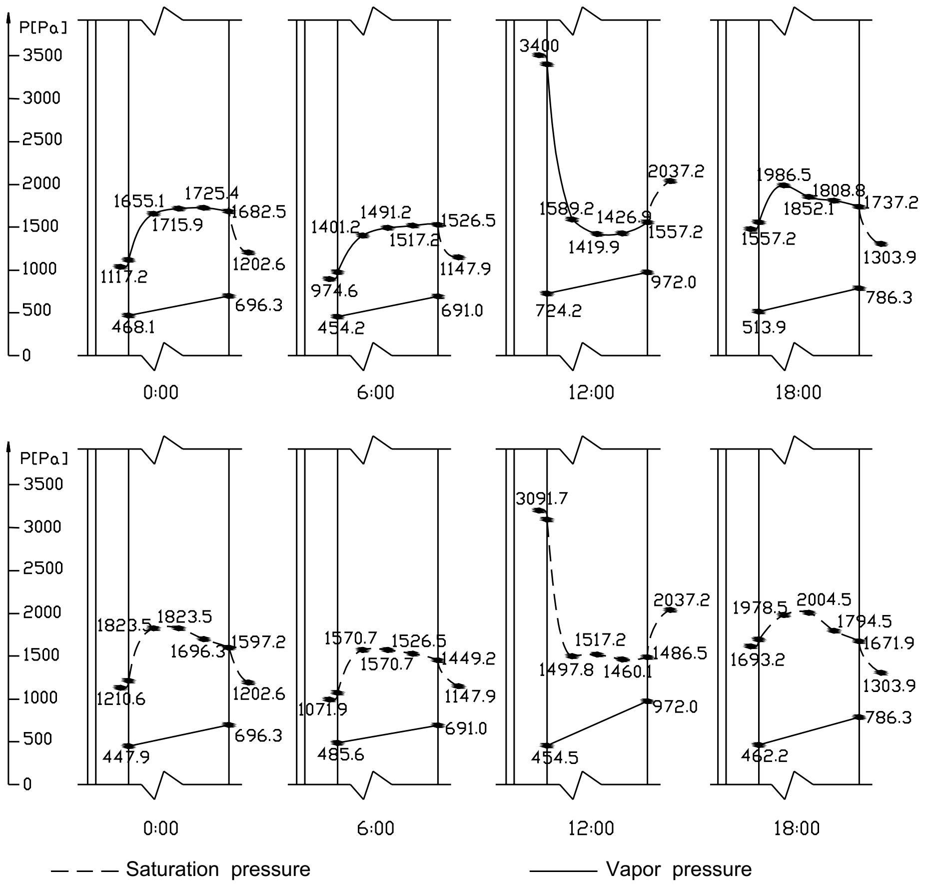


Fig. 8. Evaluation of condensation within Trombe walls of the PS cell at steady-state condition.

Figs. 7 and 8 show the calculated results, referring to Fig. 2 for the structure of the wall. It can be seen in Fig. 8, concealed condensation within the Trombe wall did not accumulate, due to the moisture migrating to the air-gap and the relatively higher temperature within the wall. However, within south façade wall of the reference cell, water vapor pressure curve approached saturate pressure curve at 0:00, 6:00 and 18:00. Calculated results show that there was no condensation within the wall (see Fig. 7).

The above analysis is carried out on the assumption of no liquid water in the walls, whereas there are much liquid water existed actually. A coupled model of vapor and liquid water transfer should be introduced to perform more accurate calculation, but the coefficient of phase change emerged in the model is dependent on the respective diffusion rate of the vapor and liquid phases, which is very difficult to determine in real operation.

3.4. The correlation between indoor air RH and outdoor environment

Fig. 9 shows the correlation of RHs between the indoor and outdoor environment from December 2003 to February 2004. It is clear that the indoor RH hardly changes with outdoor environment because of the outside Styrofoam-panel thermal insulation that has low vapor permeability as well as the doors and windows were tightly closed during most of the testing period. While the RH fluctuation in the reference cell in December was caused by ventilation.

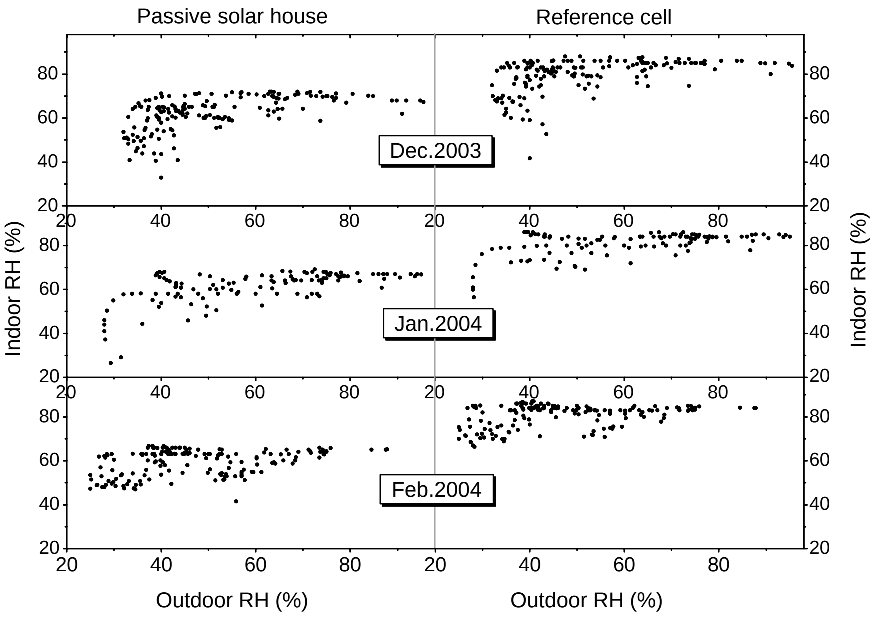


Fig. 9. Correlation between indoor air RH and outdoor environment.

4. Conclusion

Experiments have been performed in a full-scale passive solar cell constructed in the campus of Dalian University of Technology in China, and a same-scaled reference cell was also built beside the PS cell. Temperature and RH have been tested in the two cells from November 2003 to February 2004. Based on moisture transfer theory and the measured data, condensation within the wall as well as dewing of the inner surface of the doors/windows are analyzed. The moisture transfer comparison between the two cells shows that the Trombe wall in the passive solar house can finely adjust the indoor humidity. While the moisture migration to the air-gap and the low temperature of the glazing makes dewing appear on the inner surface of the glazing in the Trombe wall during the tests.

The analysis in this paper is just based on steady humidity transfer theory and the influence of the liquid water in the wall has not been considered, while more accurate calculation still needed to be developed.

References

[1] Jie Ji, Wenfa Xu. The influence of moisture transfer on thermal insulation behavior of building walls in severely cold regions. J China Univ Sci Technol 1994;24(1):114–8 [in Chinese].

[2] Zhao Li-hua, Dong Zhong-cheng, Jia Chun-xia. Moisture transfer through external insulation wall. J Harbin C.E Architect 2001;34(6):78–81.

[3] Jia CX, Zhao LH, Dong ZC. Research on moisture transfer through external insulation wall in cold climate. Insulation Mater Build Energy Saving 2001;8:1–4 [in Chinese].

[4] Xianghui Su, Haisong Ang, Feng Xu. Method for solving transient heat and moisture transfer in multi-layered building elements. Chin J Comput Phys 2003;20(4):345–50 [in Chinese].

[5] Yongcheng Chen, Qigao Chen. Analysis of moisture distribution in wet zones of building walls. J Chongqing Jianzhu Univ 1997;19(3):16–22 [in Chinese].

[6] Yongcheng Chen, Qigao Chen. Analytical solution of moisture distribution in the absorbent zone of the building envelope. J Chongqing Jianzhu Univ 1997;19(4):77–80 [in Chinese].

[7] Mingfang Tang, Qigao Chen, Jin Wang. Effect of air infiltration on moisture within a porous material layer in building envelops. J Chongqing Jianzhu Univ 1997;19(4):77–80 [in Chinese].

[8] Xiaoshu Lu. Estimation of indoor moisture generation rate from measurement in buildings. Build Environ 2003;38:665–75.

[9] Lucas Franck, Adelard Laetitia, Garde François, Boyer Harry. Study of moisture in buildings for hot humid climates. Energy Build 2002;34(4):345–55.

[10] Mendes N, Winkelmann FC, Lamberts R, Philippi PC. Moisture effects on conduction loads. Energy Build 2003;35:631–44.

[11] Jie Ji, Juwen Gao, Xinshi Ge, Hulin Huang. A new method for the calculation of dynamic moisture distribution of a moisture porous body. J China Univ Sci Technol 1994;24(3):300–4 [in Chinese].

[12] Jiaping Liu. Building physics. Beijing: China Publishing House of Building Industry; 2000 [in Chinese].