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Performance Evaluation Of Thermally Activated Glass Fibre Reinforced Gypsum Building Equipped With Desiccant System

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ABSTRACT

A thermally activated glass fiber reinforced gypsum building (1m x 1m x 1m) equipped with desiccant system is proposed and investigated for the hot and humid climatic conditions. It effectively controls the temperature and humidity of the indoor, closer to comfort condition. In the present study, the influence of temperature and flow rate of the cooling water are experimentally investigated for the thermal performance on the proposed system. The performance indices are indoor temperature, relative humidity, operative temperature, PMV and PPD. It is found that even at 38 °C (OAT), 40% (R.H) ambient condition, the proposed system maintains the comfort environment with the inlet temperature and flow rate of the cooling water as 20°C and 350 lph respectively.

1. INTRODUCTION

According to the International Energy Outlook 2017, the energy consumption of the building sector is expected to increase by 32% from 2015 to 2040 (IEO 2017). This is due to the accelerating demand for mechanical air conditioning system for maintaining the indoor comfort conditions and the high embodied energy of the conventional building materials. Many solutions are proposed globally to address these problems. Thermally Activated Building System (TABS) is one such energy efficient alternative to the conventional mechanical air conditioning system for providing the desirable indoor comfort conditions (Jae Han Lim *et al.*, 2014). In TABS, pipes are embedded in its building structures namely ceiling, floor and walls. Chilled water circulated in the pipes, cools the building structures which in turn cool the indoor environment by radiative and convective heat transfer methods. The greatest advantage of TABS system is its ability to operate at relatively higher water temperature, which permits the use of passive cooling systems for its chilled water need. Options for getting the cooling water supply are earth tunnel cooling, geothermal cooling, evaporative cooling, nocturnal cooling etc. However, TABS handles only the sensible load, which became a serious issue for hot and humid climatic condition prevailing in the city of Chennai, India. Therefore, a separate system is required for the control of indoor humidity. Desiccant system is an energy efficient option which can utilise the low grade energy sources (eg. solar or waste heat) for its regeneration requirement. In the present study, solid desiccant is proposed than the liquid desiccant to avoid the problem associated with corrosion. Therefore, a solid desiccant wheel made up of silica gel is used to control the humidity of the supply air. As the result, both temperature and relative humidity of the indoor space can be efficiently controlled using TABS and solid desiccant wheel respectively.

The building energy consumption also includes the embodied energy of the building materials (J. Monahan & J.C powell 2011). Embodied energy (i.e. Energy that was used in the work of making a product) associated with the conventional building materials is higher. In this present study, Glass Fibre Reinforced Gypsum (GFRG) is used as a building material due to its less embodied energy and low thermal conductivity. GFRG is made up of reinforced glass and gypsum. It is a lightweight and eco-friendly material and also high resistance to fire, heat, water and corrosion (Devdas Menon & A. Meher Prasad 2013). In addition, the presence of air cavities in the GFRG roof panel reduces the external solar heat penetration into the room. The combination of TABS and GFRG building is named as Thermally Activated Glass Fiber Reinforced Gypsum (TAGFRG) building. The combination of TABS and desiccant system in the conventional building as gained attention in the last decade (A.S. Binghooth & Z.A. Zainal 2012 and Yasin Khan *et al.*, 2017). However, GFRG building with TABS and desiccant system is not yet studied so far. The main objective of the present study is to experimentally evaluate the performance of the combination of TABS and desiccant wheel in the GFRG building. The study analyses the influences of various operating parameters namely temperature and flow rate of cooling water. The performance of TAGFRG is evaluated in terms of indoor temperature, relative humidity, operative temperature, PMV and PPD. The results of the present study are useful for the optimum design of TAGFRG which has the potential to reduce the energy consumption of the building sector.

2. EXPERIMENTAL SETUP AND INSTRUMENTATIONS

The schematic diagram of experimental setup is shown in Fig.1. The test room is constructed with a dimension of 1m (L) x 1m (B) x 1m (H). The experimental setup consists of two circuits namely air and water circuits. The air circuit consists of a fan, desiccant wheel and the heat exchanger. The fan sucks the fresh air from the ambient and sent it to the desiccant wheel. The air coming out of the desiccant wheel is dry and hot, therefore it is to be cooled before getting into the room. Thus, the temperature of the air is reduced by the cooling water in the heat exchanger. The velocity, temperature and relative humidity of the air are controlled using the speed of the fan, inlet temperature of the cooling water and the desiccant wheel. Ventilation rate of the proposed TAGFRG is maintained according the standards prescribed by ASHRAE.

The water circuit consists of a constant temperature bath, pump and heat exchanger. The temperature of the water is controlled using thermostat of the constant temperature bath. The pump not only helps in circulating the chilled water from the constant temperature bath to the heat exchanger but also to the copper pipes embedded in the building fabrics. In addition, the system has been provided with provisions to cut off the cooling water supply to the heat exchanger in case of no demand.

The temperature of the air and water in the system are measured using 'T' type thermocouple. It has a range of -270 to + 370 °C and an accuracy of +/- 0.75%. The indoor and outdoor relative humidity is measured using the RH meter. It has the ability to measure relative humidity ranges from 5% to 95% with an accuracy of +/- 1.5%. The flow rate of the cooling water is measured using the dial type water meter. All these values are recorded using the data acquisition system for the time period of 9.00 a.m. to 5.00 p.m.(office hours). All the sensors and instruments are pre-calibrated. The temperature sensors are calibrated using the constant temperature bath for the entire working range. The relative humidity probes are calibrated using a dew point meter in a constant environment chamber for their entire working range of different temperatures.

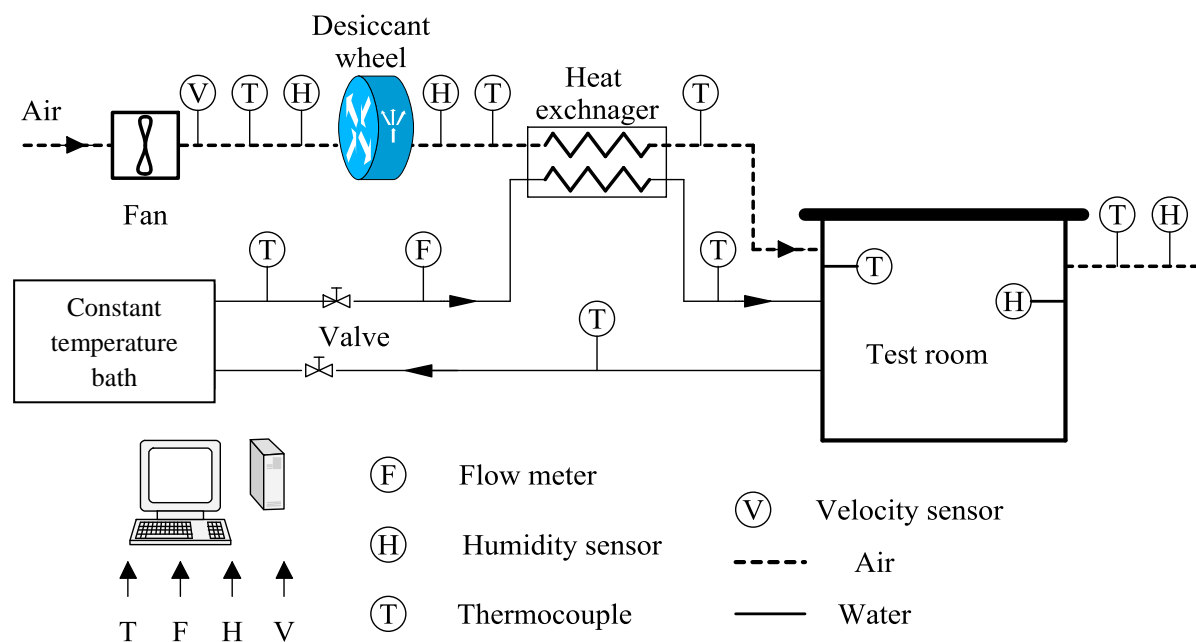


Figure 1: Schematic diagram of TAGFRG experimental setup

3. EXPERIMENTAL PLAN & PROCEDURE

3.1 Operating parameters

The operating parameters selected for the parametric study are inlet temperature and flow rate of the cooling water. Flow rate of cooling water is varied using the flow control valve provided near the pump. It is varied from 350 lph to 500 lph at the increment of 50 lph. Inlet temperature of the cooling water is varied using the

thermostat of the constant temperature bath. It water is varied from 20°C to 26°C at the increment of 2°C. The cooling water is circulated to all the surfaces of the test building which gives the better indoor thermal comfort in earlier studies (D.G. leo Samuel *et al.*, 2016). The effect of each parameter has been studied by keeping the other parameter fixed at their corresponding default values to know the trend and behaviour of TAGFRG.

3.2 Performance parameters

The performance parameters chosen are indoor air temperature, indoor relative humidity, Predicted Mean Value (PMV) and Predicted Percentage of Dissatisfied (PPD).

3.2.1 Predicted Mean Value (PMV): An index that predicts the mean value of votes of a large group of persons on a seven point thermal sensation scale. The scale ranges from cold (-3) to hot (+3). The recommended acceptable PMV range for thermal comfort from ASHRAE 55 is between -0.5 and +0.5 for an interior space.

3.2.2 Predicted Percentage of Dissatisfied (PPD): An index that establishes a quantitative prediction of percentage of thermally dissatisfied people determined from PMV. It ranges from 0% to 100 %. The recommended acceptable PPD range for thermal comfort from ASHRAE 55 is less than 10% for an interior space.

4. RESULTS AND DISCUSSION

4.1 Effect of inlet temperature of cooling water

The inlet temperature of the cooling water is an operating parameter that predominantly decides the indoor temperature of TAGFRG building. Lower values of inlet temperature of cooling water reduces the temperature of the room. However, it not only increase the primary energy consumption at the cooling system but also leads to condensation issue in hot and humid climatic conditions. On the other hand, the inlet temperature of cooling water depends on the ambient condition, if TAGFRG building is coupled with passive cooling system. Therefore, it is essential to study the influence of inlet temperature of cooling water on TAGFRG building to find an optimum value. Figure 2 shows the variation of indoor and outdoor air temperatures obtained along the given time period for different inlet temperature of cooling water.

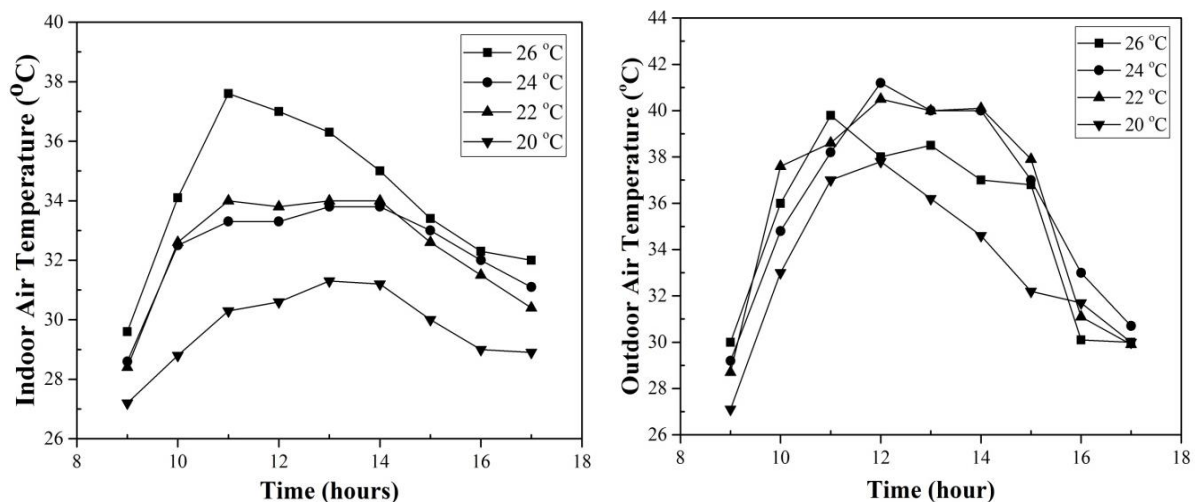


Figure 2: Variation of indoor and outdoor air temperatures for the different water inlet temperatures

The experiments are carried out on the different ambient conditions and thus the comparison of the obtained results may not be much effective. Therefore, the difference in the peak ambient and indoor temperatures (ΔT) for the given day is chosen as the parameter for the optimum selection of inlet temperature of cooling water. The ΔT values are 6.5, 5.9, 4.4 and 3.3 °C for the corresponding inlet temperature of 20, 22, 24 and 26°C respectively. In addition, the average indoor temperature for the respective cooling water inlet temperatures are 29.8, 32.6, 32.5 and 34.4°C. Therefore, the optimum value for the inlet temperature of the cooling water is selected as 20 °C based on ΔT and average indoor temperature. Figure 3 reveals the variations of indoor temperature and relative humidity at the selected (20°C) inlet temperature of the cooling water. As shown, the indoor relative humidity is maintained in the range of 45 -55 % in most of the hours which can maintain the indoor comfort as per ASHRAE standard.

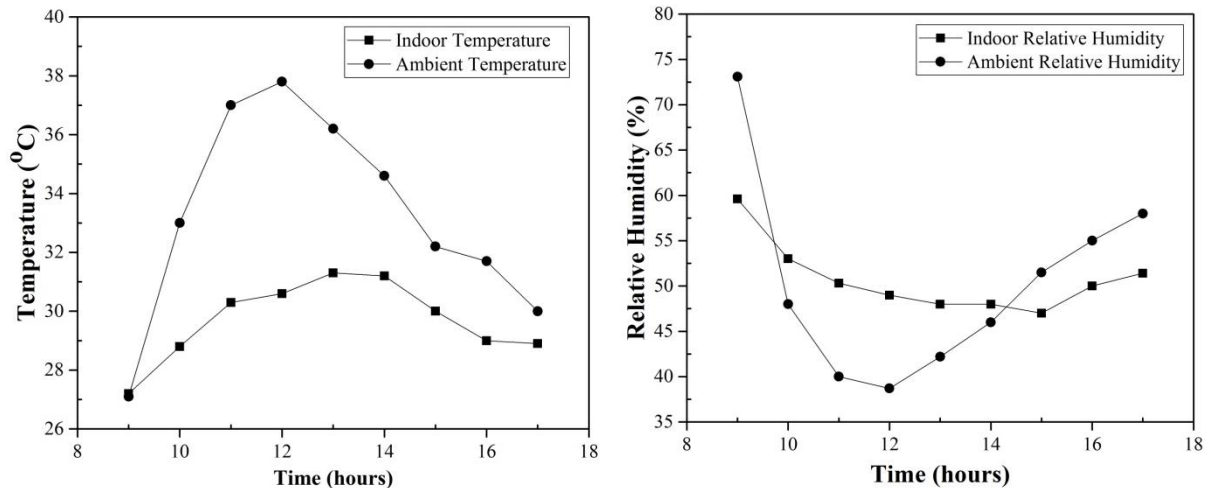


Figure 3: Variation of temperatures and relative humidity for the water inlet temperature of 20 °C

Figure 4 shows the PMV and PPD of the indoor space for different water inlet temperatures. Both PMV and PPD of the indoor space falls in neutral region for maximum period at the inlet temperature of 20°C. Therefore, reducing the inlet temperature below 20°C will lead to feel cold in the indoor space. The peak ambient temperature obtained on that particular day is 38 °C, whereas for other cases it is around 40 - 41 °C . This is the reason for the significant gap between PMV and PPD of supply temperatures of 20 °C and 22 °C as shown in fig.4.

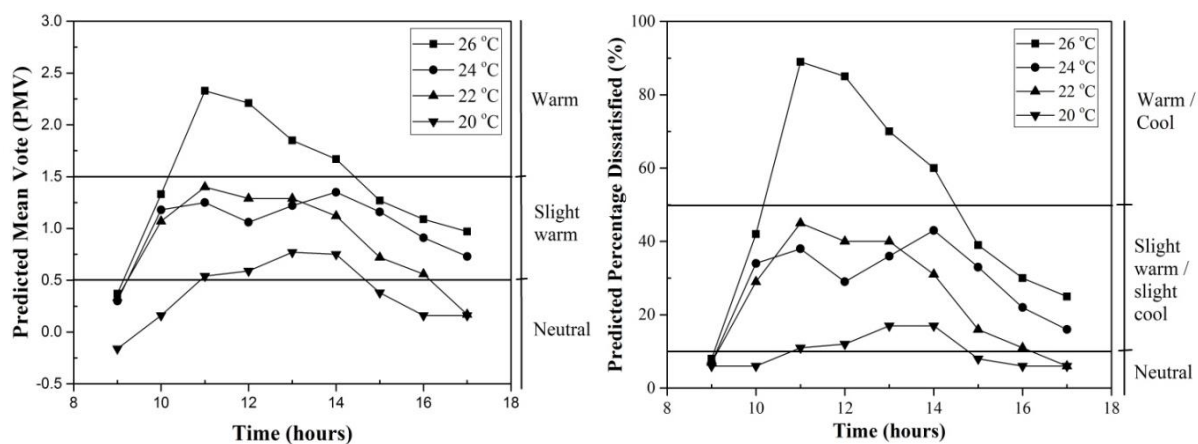


Figure 4: Variation of PMV and PPD for the different water inlet temperatures

4.2 Effect of flow rate of cooling water

The flow rate of the cooling water is one of the essential parameter that contribute to the heat transfer. For a given inlet temperature of the cooling water, if the water flow rate increases, the amount of heat transfer from the room to the circulating cooling water will also increase. However, higher flow rate increases the energy required for circulating the cooling water. On the other hand, lesser flow rate leads uncomfortable indoor environment. Thus, it is necessary to select a optimum cooling water flow rate. Figure 5 shows the variation of indoor and outdoor air temperatures for the different cooling water flow rates.

Similar to the previous parametric study of inlet temperature of cooling water, ΔT is used in this parametric study. The ΔT value for water flow rates of 350, 400, 450, and 500 lph are 6.5, 4.3, 4.2 and 5°C respectively. In addition, the average indoor temperature throughout the day for the respective water flow rates are 29.8, 30.2, 28.7, and 28.4°C. From Fig.5, it is noted that even though the outdoor temperature is higher for the flow rate of 350 lph, it has the ability to reduce the indoor air temperature for about 6.5 °C. The trend in ΔT and average indoor temperature is not uniform, therefore the present study chooses the adaptive thermal comfort model for selecting the optimum value.

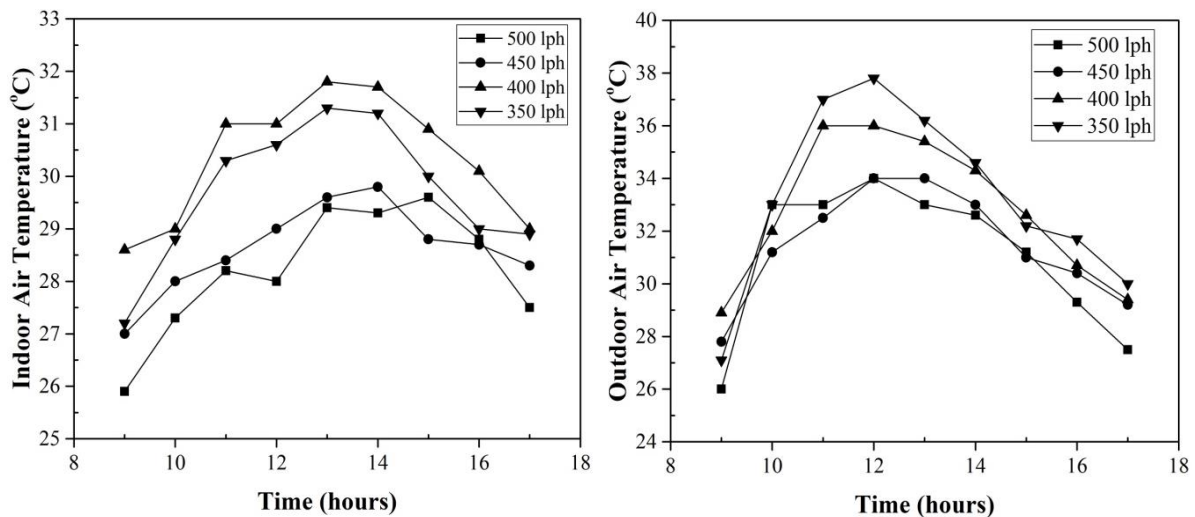


Figure 5: Variation of indoor and outdoor air temperatures for the different water flow rates

4.2.1 Adaptive Thermal Comfort: People get adapted to the thermal environment, to which they are exposed and also make adaptive changes to suit the environment. The adaptive comfort range and human adaptive behaviour to suit the local climate allows the use of passive cooling systems for thermal conditioning. So it is necessary to validate the obtained results in the adaptive thermal comfort equations too. The adaptive comfort equations underlying ASHRAE standards is,

$$T_{comfop} = [0.31 \times T_{out}] + 17.8 \quad (1)$$

where T_{comfop} is indoor comfort operative temperature (°C), T_{out} is outdoor air temperature (°C),

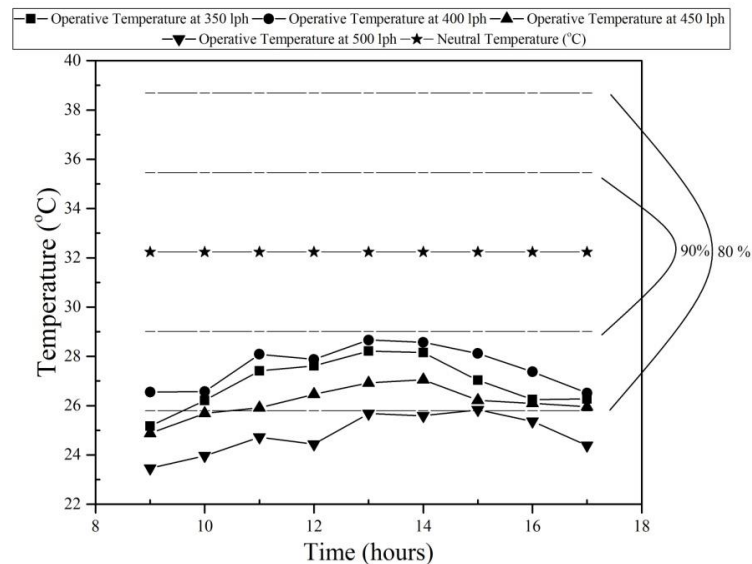


Figure 6: Variation of indoor operative temperatures for the different water flow rates

Figure 6 illustrates the variation of indoor operative temperatures along the given time period for different water flow rates. Operative temperature is the mean of mean radiant temperature and indoor air temperature. The neutral temperature lies on 32.2°C. It is noted that the indoor is maintained closer to the 90% comfort limit for water flow rates of 400 lph and 350 lph. Though the remaining water flow rates shows lesser indoor air temperature, their comfort limit goes below 85% as per adaptive thermal comfort model. Thus 450 lph and 500 lph are not preferred. It is already witnessed that the ambient temperature is higher for the case of 350 lph than that of 400 lph. Thus, with references to the ambient and indoor operative temperature of both cases, the study appreciates the flow rate of 350 lph. Figure 7 depicts the variation of indoor temperature and relative humidity

along the given time period for the water flow rate of 350 lph. It is observed that this water flow rate has the ability to maintain both temperature and relative humidity within the comfort limit for maximum period.

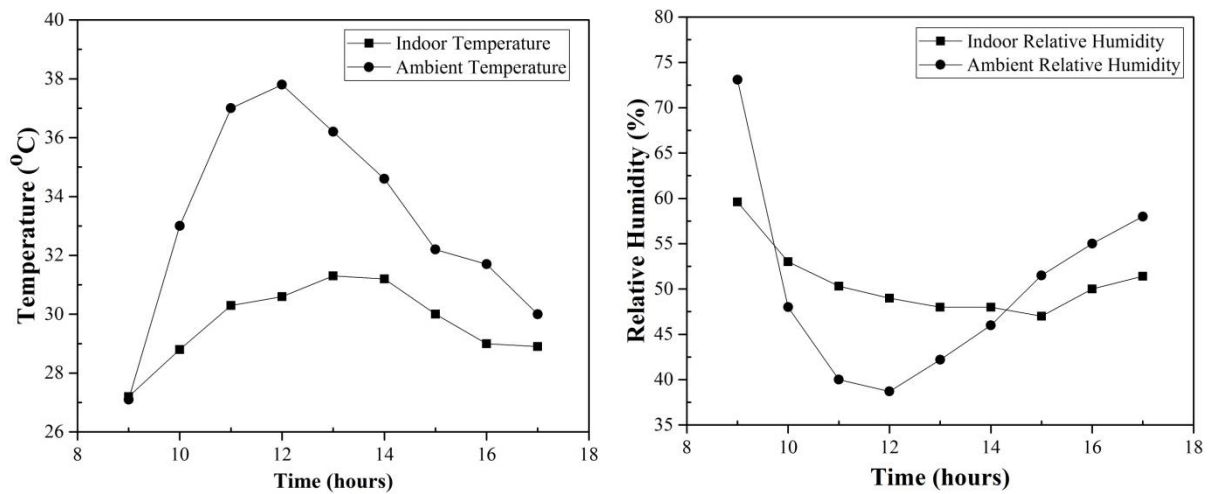


Figure 7: Variation of indoor temperature and relative humidity for the water flow rate of 350 lph

5. CONCLUSION

The present experimental study proposed thermally activated glass fiber reinforced gypsum building equipped with desiccant system for hot and humid climatic condition prevailing in the city of Chennai, India. The effect of inlet temperature and flow rate of the cooling water on the proposed system are studied. The performance of the system is presented in terms of indoor temperature, indoor relative humidity, PMV and PPD. The difference in the peak ambient and indoor temperatures (ΔT) along with the indoor operative temperature also contribute in the comparison of the thermal performance. It is found that increase in water flow rate and decrease in water inlet temperature, increases the indoor thermal comfort. The results shows that the TAGFRG maintains a comfort indoor environment when operating at cooling water inlet temperature of 20 °C, flow rate of 350 lph and all surfaces cooling scenario in the hot and humid climatic region for a maximum ambient temperature of 38°C.

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