Feasibility study of the passive solar room dehumidifying system using the sorption property of a wooden attic space through field measurement

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ABSTRACT

Substantial effort has recently been devoted to passive solar desiccant air dehumidification. This research aims to describe the passive room dehumidifying system with the combination of an existing wooden attic space as a chamber and desiccant; an optimization of ventilation system and solar energy as system operation. The field measurement was carried out in the test house in Japan over hot humid summers in 2003 and 2004. It was found that the dehumidification rate of the wooden attic space was approximately 25 g/h per square meter of floor area of attic space. The electric coefficient of performance was approximately 15. In addition to the attic space, regarding to the investigation on the system including the ventilation between the attic space and the bedroom, in the presence of an occupant, the humidity of the bedroom during the nighttime was lower compared to the traditional natural ventilation approach throughout the night. Therefore, the system outlined in this study could be promising as a new passive tool for moisture control in hot humid region.

1. INTRODUCTION

In hot humid regions, air dehumidification is considered to be an issue of increasing concern as an important aspect of indoor environment. A good air dehumidification is crucial to moisture related problems, e.g. human health and comfort, building energy performance and building durability and maintenance. At the present, an air conditioning system plays an important part in decreasing air humidity and has become a necessity for almost all buildings. However, it often consumes a great deal of energy and releases CFCs of HCFCs, which is harmful to environment.

To produce an alternative solution to this issue, desiccant dehumidification applications have been studied by several researchers whose studies were reviewed (Waugaman et al., 1993). Of particular interest are those with passive approach, using solar energy to regenerate desiccant materials. With regard to the fundamentals of desiccant, it initially attracts moisture from surrounding air until equilibrium state with the surrounding moisture is reached. In order to attract moisture once again, the desiccant needs to be dried or so technically called regeneration process. A typical regeneration process includes heating and exposure to scavenger air stream. As this cycle repeats, the moisture in air absorbed by the desiccant could be defined as the level of air dehumidification. In these systems, the chamber of the system consists of netting solid desiccant bed. During nighttime, the desiccant bed dehumidifies air and releases sensible heat due to an absorption process through nocturnal radiation. During daytime, the bed is regenerated by solar energy and exhaust ventilation and ready again for air dehumidification in nighttime.

In addition to commercial chemical desiccant materials, natural fiber materials such as kenaf core (Williams, 1991), coconut coir and durian peels (Khedari et al., 2003), can attract and hold water as commercial chemical desiccants. Wood has also been investigated as potential desiccant material in many studies. It is demonstrated that moisture transfer between indoor air and wood based hygroscopic material could reduce the daily peak indoor humidity (Simonson et al., 2002). Furthermore, wood based material has enough potential to keep the room humidity below 60% for a period of time after the air conditioning system is switched off (Sakamoto and Zhu, 1996).

Although a great deal of research has been done on air dehumidification with mechanical equipment which requires high cost investment and degradable commercial chemical desiccant material, little research on passive air dehumidification using building component, such as a wooden attic, in existing building has yet been done. This paper reports on the results in an attempt to describe the passive room dehumidifying system with the combination of an existing attic space as a chamber; wood as a desiccant material; an optimization of ventilation and solar energy as a system operation.

2. CONCEPT OF THE ROOM DEHUMIDIFYING SYSTEM

In Figure 1, the operation of the system during daytime and nighttime is illustrated. An airtight wooden attic space plays a role as a chamber while wood compositions of the attic, especially plywood underneath roof material, work as desiccant material. During daytime, high temperature in the attic space regenerates wood and

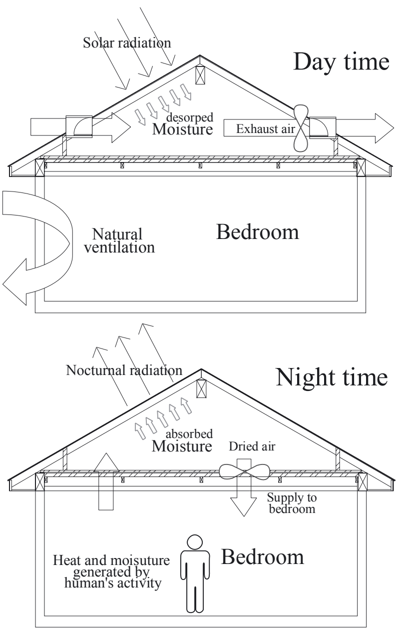


Figure 1: Schematic view of the operation of the system during day and nighttime.

moist air is to be vented out by exhaust ventilation. Inversely, during nighttime, low moisture content generated during daytime induces wood to adsorb moisture from humid air, supplied from the bedroom while sensible heat of the absorption process relieved through nocturnal radiation. Here, the moisture load from the bedroom represents the latent heat production of human's activity. After the air is dried by the absorption process of the attic space, it is subsequently fed back into the bedroom. This cycle is repeated throughout nighttime. The decrease in air humidity of the bedroom during nighttime due to the moisture absorption of the attic space is taken into consideration as the quantity of dehumidification.

3. EXPERIMENT METHOD

The measurement was conducted during the hot humid season in the test house in an open suburban area of Saitama city, Japan (latitude 36°00’N, longitude 139°12’E). As a preliminary study, the dehumidification potential of the wooden attic space alone was investigated in 2003. In addition to the attic space, the investigation on the system including the ventilation between the attic space and the bedroom was performed in 2004. Here, our main target of dehumidification is the bedroom.

3.1 Building Description

The two-story north-south oriented wooden structure building, which is illustrated in Figure 2, is mainly comprised of four rooms which two main rooms on each floor, a staircase and an attic space. The main room on 2nd floor is assumed as the bedroom in this study. All connections between rooms were closed while measurements were performed. Particularly the connection between the attic space and the other rooms is assumed to be hermetic sealed besides the ventilation of the system. Additionally, in order to eliminate the effect of the sorption property of the components of the bedroom, vinyl sheet was attached to all component surfaces. The configuration of the attic space is illustrated in Table 1.

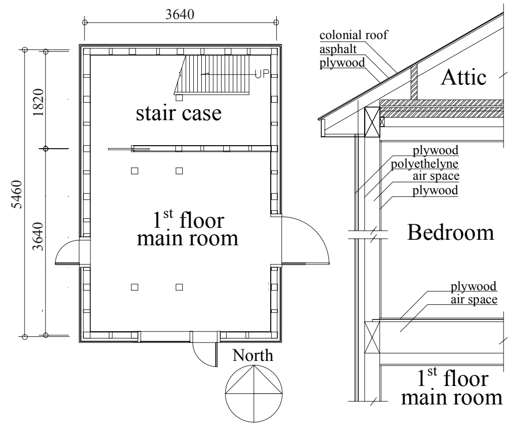


Figure 2: Plan and section view of the test house.

Table 1: Characteristics of the attic space and bedroom of the test house.

	Attic space	Bedroom
Floor area (m^2)	19.87	13.25
Height (m)	1.15	2.40
Room volume (m^3)	11.50	31.75
Air infiltration (cm^2/m^2)	0.70	1.00

3.2 Measurement and Control

3.2.1 Experimental Instruments and Parameters

Thermo couples and salt-phase heated hygrometers (Dew-cell) were applied to measure temperature and humidity as main dependent parameters in this study. Furthermore, ventilation rate measured by tracer gas monitors (Bruel and Kjaer type 1312, 1303) and small anemometers along with heat and moisture generation played a role as control parameters. For gathering and storing measured data, the data acquisition was set up in the container room close to the test house and monitored by using an interval time of 1 minute.

3.2.2 Control and Operation

To control parameters, the set of equipments was setup. With regard to the daytime exhaust ventilation, two dampers were installed in both the north and south gable walls along with weather cover hoods. Additionally, one fan installed at the north gable wall, with a capacity of 470 m^3/h, was employed to induce the exhaust ventilation. For the ventilation between the attic space and bedroom, the ventilation fan with a capacity of 250 m^3/h was installed at bedroom ceiling for

Table 2: Operation mode for the investigation on the standalone wooden attic space.

Operation mode	Daytime exhaust ventilation	Nighttime heat and moisture generation
Mode1	No	No
Mode2	No	Yes
Mode3	Yes	Yes

Table 3: Operation mode for the investigation on the whole system.

Operation mode	Daytime natural ventilation of bedroom	Nighttime natural ventilation of bedroom	Daytime exhaust ventilation of attic	Nighttime ventilation between attic and bedroom
Mode4	Yes	No	Yes	Yes
Mode5	Yes(high)	Yes(high)	No	No
Mode6	Yes(low)	Yes(low)	No	No

exhausting air from bedroom to attic space along with another opening for the purpose of supplying back the air to the bedroom. To reduce temperature and humidity stratification in the attic space, 7 small ventilation fans were installed in the attic space with one ventilation fan in the bedroom. Furthermore, to simulate the effect of a sleeping adult in the building, the humidifier and heat generator produced approximately moisture of 60 g/h and sensible heat load of 100 W respectively as a constant rate.

In the investigation on the attic space alone, 3 operation modes that differ in the operation of the daytime exhaust ventilation and the nighttime heat and moisture generation were investigated as shown in Table 2. Mode1 aimed to describe the nature of the sorption property of the attic space. In addition, by comparing Mode2 and Mode3, the effect of the daytime exhaust ventilation on the dehumidification potential of the wooden attic space is determined. Furthermore, 3 operation modes were set up for the investigation of the whole system as shown in Table 3. Mode4 describes the result of this system while Mode5, 6 simulate that of the natural ventilation with high and low ventilation rate respectively.

In the presence of the daytime exhaust ventilation of the attic space, the dampers played a major role in controlling ventilation as well as the exhaust fan. The dampers and fan were programmed to open when the level of the absolute humidity of the attic space exceeded that of outdoor air to exhaust the moist air and close vice versa to allow the absorption process to begin. On the other hand, in the operation mode with the absence of the daytime exhaust ventilation, the dampers were always closed regardless of the level of absolute humidity. In addition, in the presence of the nighttime sensible heat, moisture generation and ventilation between the attic space and bedroom, they were operated 8 hours a day, from 10 p.m. until 6 a.m. of the next day. The high and low ventilation rates in natural ventilation Mode 5, 6 were induced by opening east-west windows and sole east window of the bedroom respectively.

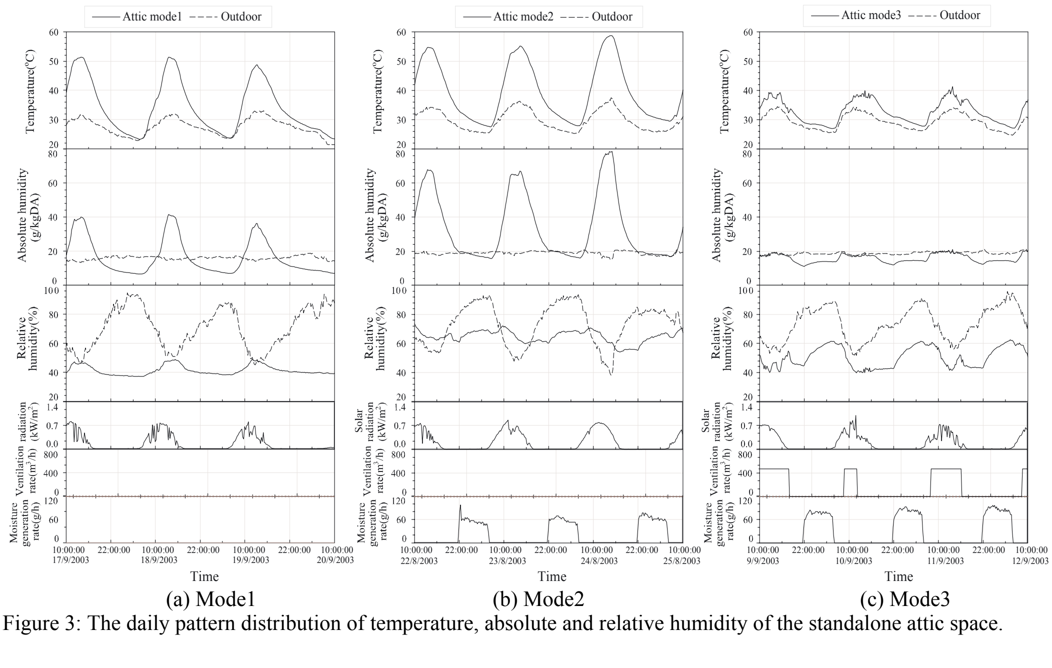
4. RESULTS AND DISCUSSIONS

Results and discussions are categorized into two parts as the measurement of the standalone wooden attic space measured in 2003 and the whole system measured in 2004.

4.1 The Standalone Wooden Attic Space

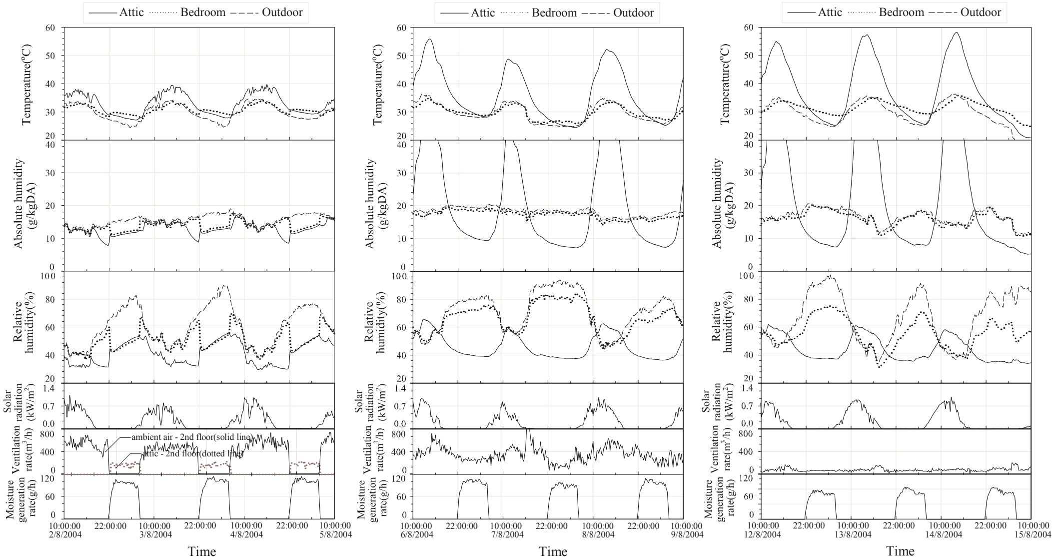
Figure 3a indicates the daily pattern distribution of temperature, absolute and relative humidity in Mode1. Apparently, there was a clear absolute humidity variation of 30 g/kg between daytime and nighttime. Furthermore, the level of the absolute humidity in the attic space approached lower than that of outdoor throughout the night by approximately 8 g/kg. This phenomenon can be explained that during the daytime, high temperature especially in roof components induces wood to release moisture into the attic space and vice versa during the nighttime. Consequentially, it significantly confirms the sorption potential of the attic space through this study.

Figures 3b, c indicate the daily pattern distribution of temperature, absolute and relative humidity in Mode 2-3. In absence of the daytime exhaust ventilation, the absolute humidity during the nighttime remained close to that of outdoor, while in the presence of the exhaust ventilation, the absolute humidity of the attic space was kept much below than that of outdoor air all night even though the heat and moisture generation were applied. Moreover, while the relative humidity of outdoor air reached 90% during the nighttime, that of the attic space in case of presence and absence of exhaust ventilation were retained below 60% and 85% respectively. Evidently, these results indicate that the absorb potential of the attic space during the nighttime, due to the presence of the daytime exhaust ventilation, can maintain the level of absolute humidity in the attic space lower than outdoor and keep the relative humidity below 60% through-



(a) Mode1 (b) Mode2 (c) Mode3

Figure 3: The daily pattern distribution of temperature, absolute and relative humidity of the standalone attic space.



(a) Mode4 (the system) (b) Mode5 (natural ventilation (high)) (c) Mode6 (natural ventilation (low))

Figure 4: The daily pattern distribution of temperature, absolute and relative humidity of the whole system.

out the period of moisture generation in the nighttime.

4.2 The Whole System

Figures 4a, b, c illustrate the daily pattern distribution of temperature, humidity while operating the system, high and low ventilation rate of natural ventilation respectively. By comparing the result of the system with the high and low ventilation rate of natural ventilation operations, even in the presence of the nighttime heat and moisture generation, apparently the absolute humidity of the bedroom when operating the system were lower by 5 g/kg than outdoor while that of the natural ventilation operations had a certain parallel with outdoor air. Furthermore, by operating the system, the level of the relative humidity of the bedroom was under 50 % throughout the night while the natural ventilations were over 60 %. However, the temperature of the bedroom by operating system was higher comparatively. Therefore, it can be inferred that the system has sufficient dehumidification potential to lower the humidity of the bedroom during the nighttime comparing to the natural ventilation.

In addition, for the purpose of system evaluation, the calculation of dehumidification rate based on the summation of the humidity change of processed air (differentiating the moisture of air supplied from the attic space to the bedroom and that of air exhausted vice versa) is shown in equation (1). In order to calculate the moisture flow, the velocity and absolute humidity, which were measured by the anemometers and hygrometers installed in the openings for exhausting and supplying air between the bedroom and attic, were applied.

$$D = \rho_a \left(v_E A_E X_E - v_S \rho_a A_S X_S \right) \qquad (1)$$

where:

- D: dehumidification rate (g/h),
- v: velocity (m/h),
- ρ_a: Air density (kg/m^3),
- A: area of opening (m^2),
- X: absolute humidity of outdoor (g/kgDA),
- E: exhaust from bedroom,
- S: supply to bedroom.

As illustrated in Figure 5, besides the start period of the operation, the dehumidification rate of the system maintained unvaried at 500 g/h, which is equal to approximately 25 g/h per square meter of attic floor area throughout the night. The dehumidification rate of 500 g/h could be considered that while the absolute humidity of the bedroom was likely constant throughout the night, apart from moisture generation of 100 g/h

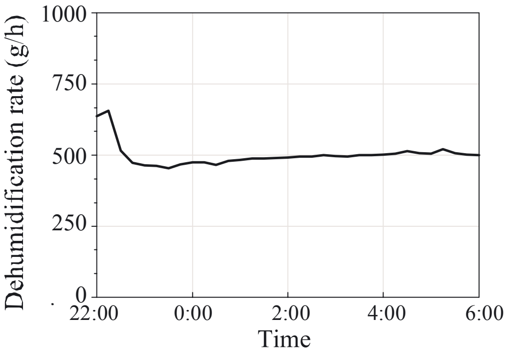


Figure 5: Dehumidification rate of the system during the nighttime.

and moisture gained due to air infiltration of 150-250 g/h, another 150-250 g/h would be the moisture desorbed from the components of the bedroom although it was expected that the vinyl sheet attached on all component surfaces could prevent moisture desorption.

Since the system operation is completely a daily cycled, it would be the most efficient evaluation to make use of daily coefficient of performance (COP). Based on the summation of latent heat change of processed air, the change in latent heat of processed air was estimated to be approximately 4,722 Wh per day. On the other hand, the electric consumption by means of one exhaust fan operated during the daytime and one ventilated fan operated during the nighttime, operated for about 8 hours of each, was approximately 330 Wh per day. As a result, the electric coefficient of performance of this passive dehumidification system was considered to be relatively high as approximately 15, which is 3 times as more than the normal dehumidification system is. The utilization of free renewable solar energy as a major advance in COP would be the most likely reason for this finding.

5. CONCLUSIONS

The significant dehumidification potential of the passive solar room dehumidifying system was realized by means of field measurement. It can be inferred that the system has relatively high dehumidification potential to lower the humidity of bedroom during nighttime comparing to natural ventilation approach. Therefore, the system outlined in this study could be an alternative tool for moisture problem. However, it is also worth mentioned that parametric study is needed to achieve the optimization of the system as well as discussion on comfort caused by the system.

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