THERMAL ENVIRONMENT OF THE HOUSE WITH A MOISTURE-ABSORBENT TYPE DEHUMIDIFIER IN SUMMER

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ABSTRACT

If an insulated and airtight house is cooled by passive ventilation using buoyant convection, the indoor air temperature can be kept lower than the outdoor air temperature, but there is a tendency for the indoor humidity to remain at a high level. In this study, the thermal environment in a house in which a dehumidifier is used in summer is numerically calculated, and the performances of various dehumidifiers are examined. The results shows that a moisture-absorbent type dehumidifier, which has a low cooling load, can create a comfortable indoor thermal environment in summer. Moreover, in the case of insulated and airtight houses, the use of a moisture-absorbent type dehumidifier enables the indoor environment of the house to be controlled by the use of natural energy instead of a heat pump.

INTRODUCTION

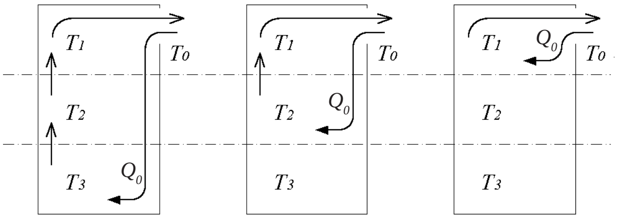
Hokkaido is the northernmost island in Japan. Although the summer in Hokkaido is short and usually cool, the outdoor air temperature sometimes rises to over 30 degrees centigrade. Recently, construction of insulated and airtight houses has been become popular in Hokkaido. These properties make the house warmer and more comfortable in winter, but they are not effectively used in summer.

Passive ventilation by buoyant convection is one method for controlling the indoor environment of a house in summer. Although passive ventilation enables the indoor air temperature to be kept lower than the outdoor air temperature in the daytime, there is a tendency for the indoor relative humidity to remain at a high level. One way of reducing indoor humidity is to use a dehumidifier inside the house.

In this study, the thermal environment in a house in which passive ventilation by buoyant convection and a dehumidifier are used in summer is numerically calculated, and the performances of various dehumidifiers are examined.

ANALYSIS METHOD & MODELS

The analysis in this study uses the Successive Integration Method[1)] and the Three-Layer Model. It is important to calculate the vertical difference of air temperature in the room that is passively ventilated by buoyant convection. Thus the space that is passively ventilated is divided into imaginary divisions comprising top, middle and bottom layers. The heat transfer with respect to the constituent walls is separated into the convection component and the radiation component[2)]. The radiation component is not absorbed into separation planes between layers. And each layers has the heat and airflow balance. Figure 1 shows the concept of fresh air flow in the Three-Layer Model. The wall surfaces do not emit or absorb vapor. Because moisture carried from outside by passive ventilation is very large compared with amount of moisture vapor absorption of walls, that is, vapor capacity of walls have a smaller influence on the thermal environment in the space ventilated well. The basic expression is shown on the next page.



(a) $T_0<T_3$ (b) $T_3<T_0<T_2$ (c) $T_2<T_0<T_1$

$$Q_0 = \frac{\alpha W H}{3}\sqrt{\frac{2gH\left|\gamma_0-\gamma_1\right|}{\gamma_0+\gamma_1}}$$

Q_0 : amount of air flow [m^3/s] α : coefficient of discharge
W : width of opening [m] H : height of opening [m]
g : acceleration of gravity [m/s^2] γ_i : density [kg/m^3]

Figure 1 Concept of fresh air flow in the 3-Layer Model

Heat balance equation in spaces

$$c\gamma_i V_i \frac{d\theta_i}{dt} = \sum_{SW} \alpha_{cl} A_l (\theta_l - \theta_i) + \sum_{NS} c\gamma Q_{ji} (\theta_j - \theta_i) + W_i$$

Moisture balance equation in spaces

$$\gamma_i V_i \frac{dx_i}{dt} = \sum_{NS} \gamma Q_{ji} (x_j - x_i) + Z_i$$

Heat balance equation on wall surfaces

$$A_k (H_m - H_k) + \alpha_{ck} A_k (\theta_j - \theta_k) + \varepsilon_k \sum_{SW} \beta_{lk} \alpha_{rk} (\theta_l - \theta_k) + W_k = 0$$

c : specific heat [kcal/kg℃] γ : density [kg/m^3]
V : volume of a room, layer [m^3] θ : temperature of air, wall surface [℃]
α_c : coefficient of heat transfer by convection [kcal/m^{2}h℃]
α_r : coefficient of heat transfer by radiation [kcal/m^{2}h℃]
Q_{ji} : amount of ventiation from j to i [m^3/s]
W : heat gain (solar radiation, human body, cooling, etc.) [kcal/h]
Z : moisture gain (human body, bathroom, dehumidification, etc.) [g/h]
x : humidity ratio of air [g/kg'] A : area of wall surface [m^2]
H_k : absorption heat flux on wall surface by Successive Integration Method [kcal/m^{2}h]
H_m : transmission heat flux on wall surface by Successive Integration Method [kcal/m^{2}h]
ε_k : absorbtivity of wall surface β_{lk} : radiation exchange coefficient

j : number of next space of space - i, the space which wall surface - k faces, outside
l : number of wall surface faced space - i and wall surface - k
NS : next spaces SW : surrounding walls

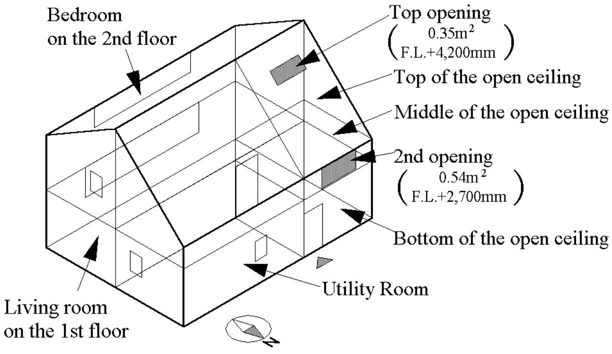
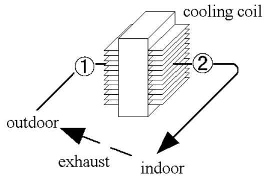
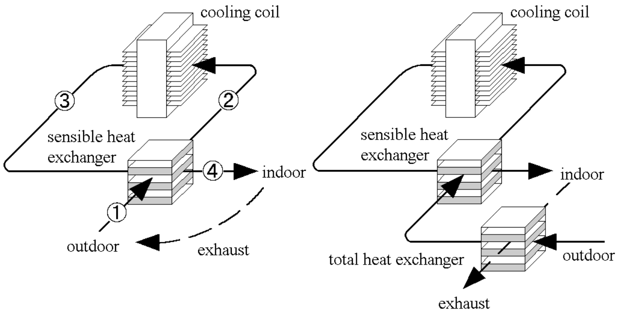


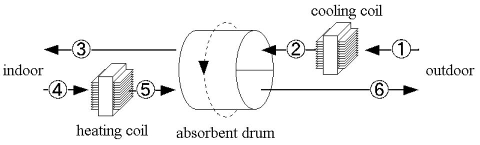
Figure 2 The house model



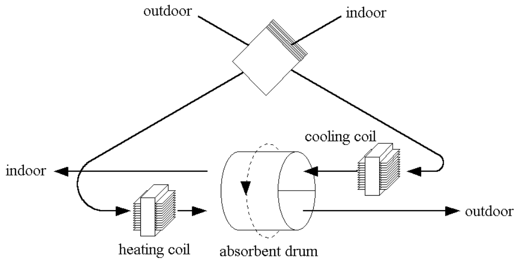
(1) Standard Type



(2) Heat-Recovery Type-1 (3) Heat-Recovery Type-2



(4) Moisture-Absorbent Type-1



(5) Moisture-Absorbent Type-2

Figure 3 Dehumidifying system tested in this study

Figure 2 shows the model house used for the simulation in this study. The house is located in Sapporo. It has two stories with an open ceiling that has two windows (a top opening and second opening at middle height) through which warm air can be exhausted and fresh air can be drawn into the house by buoyant ventilation[2]. The house has a living room on the first floor, bedrooms on the second floor, and a utility room. Four people live in the house. The hourly data of the outdoor climate (i.e., outdoor air temperature, relative humidity and solar radiation) are the averages over the hottest two-week period in summer in Sapporo. Direct solar radiation is shielded by the eaves.

Figure 3 shows the five dehumidifying systems examined in this study. The standard type has a heat pump, and it is generally used. The heat-recovery type has a sensible heat exchanger in addition to a heat pump (the type-2 system includes a total heat exchanger)[3]. The moisture-absorbent type consists of a heat pump and an absorbent drum (the type-2 system includes a total heat exchanger). In the experiments, the absorbent drum, made from corrugated cardboard with calcium chloride ($CaCl_2$), is rotated at one revolution per ten minutes to emit and absorb vapor[4]. Figure 4 shows the changes in air temperature and humidity with the use of the standard type and heat-recovery type-1 dehumidifying systems, and Figure 5 shows the changes in air temperature and humidity with the use of the moisture-absorbent type-1 dehumidifying system. The numbers in Figures 4 and 5 indicate the air-conditioning process in each of the dehumidifying systems presented in Figure 3. In the simulations, the refrigerating capacity of the

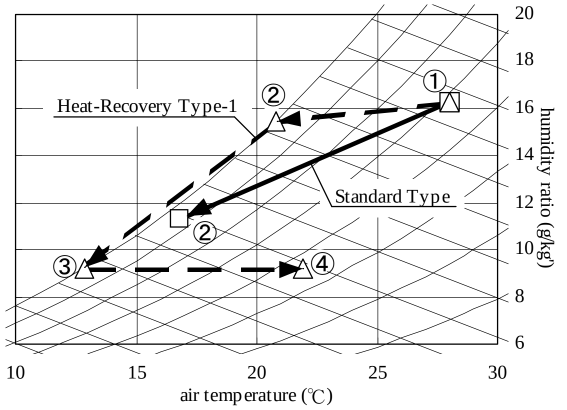


Figure 4 Changes in air temperature and humidity in the Standard type and Heat-Recovery Type-1

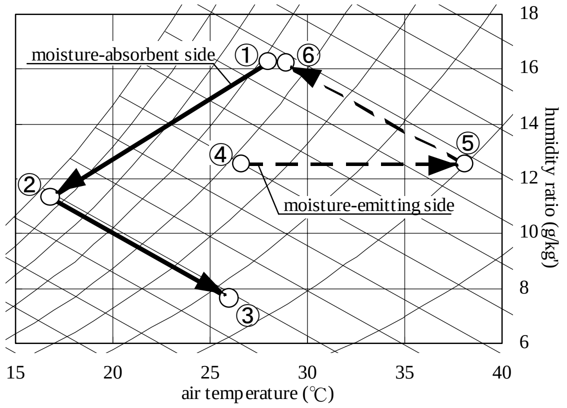


Figure 5 Changes in air temperature and humidity in the Moisture-Absorbent Type-1

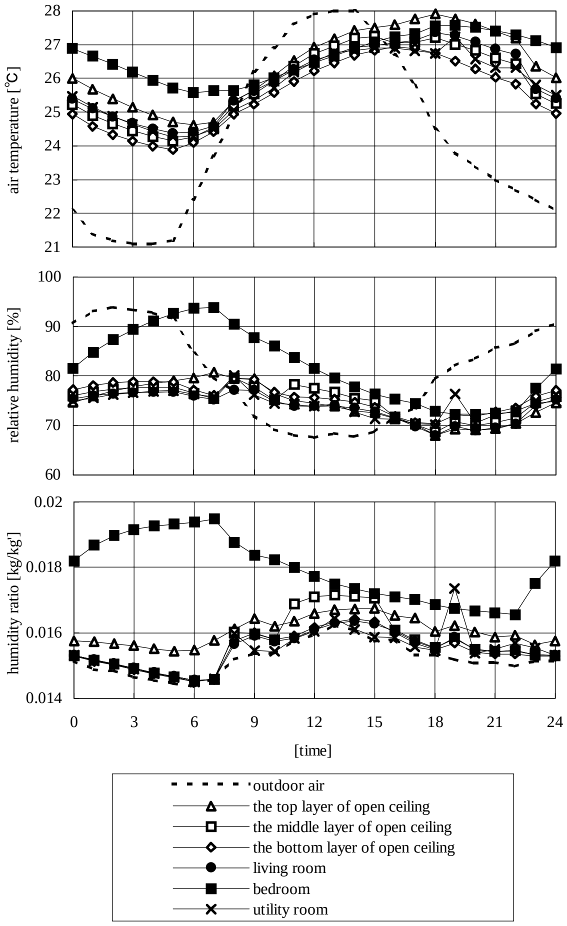


Figure 6 Indoor environment of the house without the use of a dehumidifier

dehumidifying systems is assumed to range from 100W to 600W, and the coefficient of performance of the refrigerator is 2. The coefficient of heat exchange of the sensible heat exchanger and the total heat exchanger is estimated to be 0.6. Based on experimental results, the coefficient of humidity exchange in the absorbent drum is estimated to be 0.9[4]. The coefficient of humidity exchange, based on the fact that the absorption and emission of vapor are caused by difference in relative humidity, is defined as follows.

$$\eta = (\phi_1 - \phi_3) / (\phi_1 - \phi_2)$$

η : the coefficient of humidity exchange

ϕ_1 : relative humidity after cooling [%]

ϕ_2 : relative humidity after heating [%]

ϕ_3 : relative humidity after dehumidification [%]

In the case of the moisture-absorbent type dehumidifier, the heat generated from the condenser of the heat pump is used at the heating coil, but the temperature of supplied air is kept below room temperature for the purpose of not depraving the thermal environment.

SPECIFICATION

Figure 6 shows the indoor environment of the house without the use of a dehumidifier under the conditions of an outdoor air temperature of 21.1 to 28.0 degrees centigrade and an outdoor relative humidity of 67 to 94%. Under these conditions, the air temperature in the living room and the bottom layer of the open ceiling can be kept low during the daytime, but the relative humidity remains high (from 70 to 80%) throughout the day. Moreover, the air temperature and humidity in the bedroom on the second floor at night are higher than those in other rooms due to the small amount of ventilation in this room. Thus, it is important to dehumidify the air in the bottom layer during the daytime and the air in the bedroom at nighttime. Simulation is carried out under the assumption that the dehumidifier is operated all day, with dehumidified air being supplied to the living room from 6:00 to 21:00 and to the bedroom on the second floor from 21:00 to 6:00, and the amount of ventilation is 50m^3/h.

RESULTS & DISCUSSION

The results of simulation are presented as the average values obtained during the daytime hours of 12:00 to 15:00 and average values during the nighttime hours of 0:00 to 3:00.

Figure 7 shows the relation between the cooling load of each type of dehumidifier and the relative humidity in the living room during the daytime. Figure 8 shows the relation between the cooling load of each type of dehumidifier and humidity ratio, and Figure 9 shows the relation between cooling load and amount of dehumidification during the daytime. When the standard type dehumidifier is used, relative humidity in the living room is only reduced to 70% if the refrigerating capacity is 600W. However, if the heat-recovery type dehumidifier is used, relative humidity can be reduced to about 60% at refrigerating capacity of 500W. In the case of the moisture-absorbent type dehumidifier, relative humidity of about 60% can be achieved by using type-1 at a refrigerating capacity of 300W or by using type-2 at a refrigerating capacity of 200W.

Figure 10 shows the relation between the cooling load

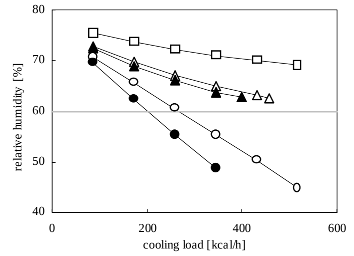


Figure 7 cooling load and relative humidity in the living room (12:00 - 15:00)

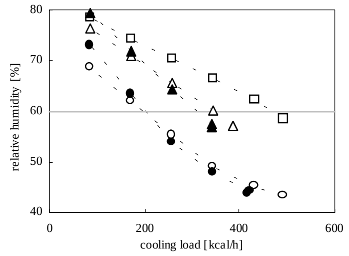


Figure 10 cooling load and relative humidity in the bedroom (0:00 - 3:00)

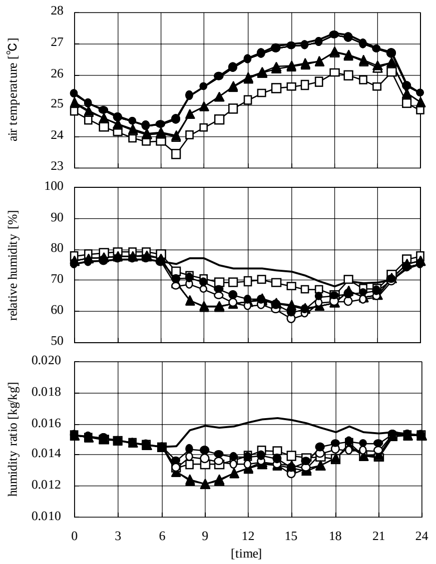


Figure 14 Thermal environment in the living room

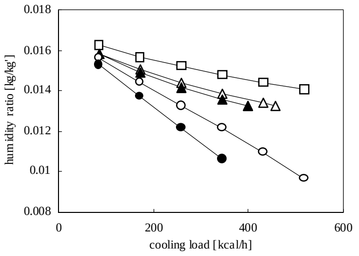


Figure 8 cooling load and humidity ratio in the living room (12:00 - 15:00)

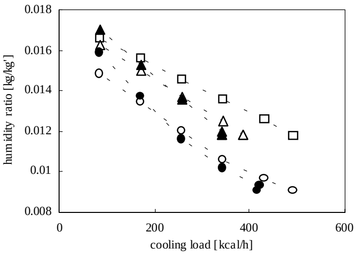


Figure 11 cooling load and humidity ratio in the bedroom (0:00 - 3:00)

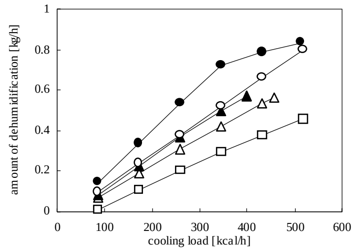


Figure 9 cooling load and amount of dehumidication in the living room (12:00 - 15:00)

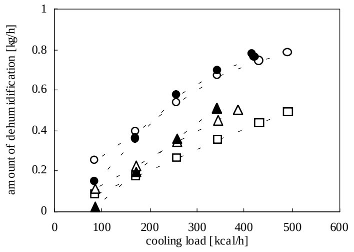


Figure 12 cooling load and amount of dehumidication in the bedroom (0:00 - 3:00)

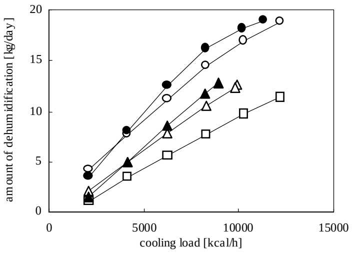


Figure 13 cooling load and amount of dehumidication through the day

□ Standard Type △ Heat-Recovery Type-1
▲ Heat-Recovery Type-2 ○ Moisture-Absorbent Type-1
● Moisture-Absorbent Type-2
——— living room - - - - - - bedroom

Table 1 Supplied air temperature

Temp. [℃]	Standard Type	Heat-Recovery Type		Moisture-Absorbent Type	
		Type-1	Type-2	Type-1	Type-2
	600W	500W	500W	300W	200W
MAX	11.9	20.6	19.2	26.0	26.0
min.	8.0	15.6	16.9	24.6	24.6
Ave.	9.4	17.7	18.1	25.9	25.9

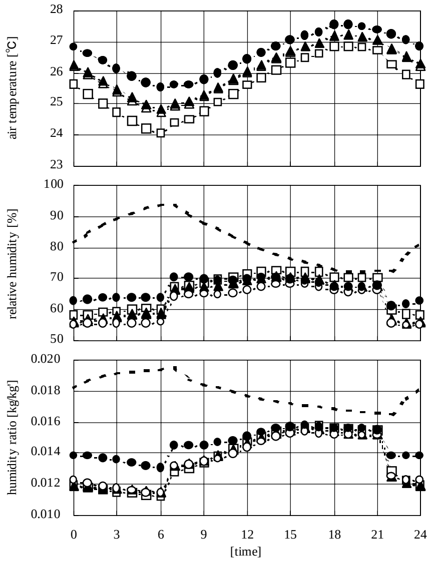


Figure 15 Thermal environment in the bedroom

——— non-dehumidification
□ Standard Type, 600W
△ Heat-Recovery Type-1, 500W
▲ Heat-Recovery Type-2, 500W
○ Moisture-Absorbent Type-1, 300W
● Moisture-Absorbent Type-2, 200W
- - - - - - - living room
——— bedroom

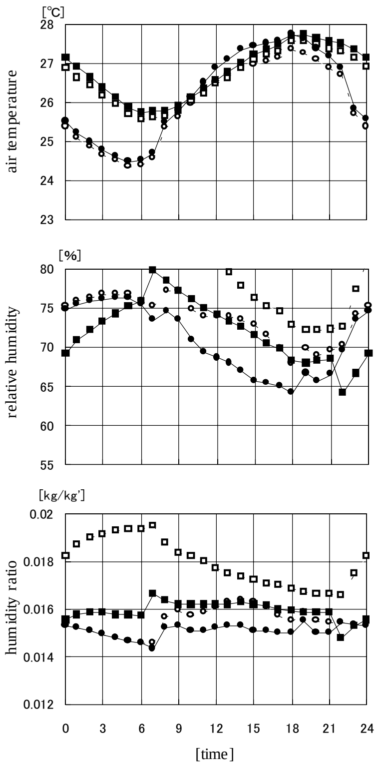


Figure 16 Thermal environment in case 1 (hothouse + cool tube)

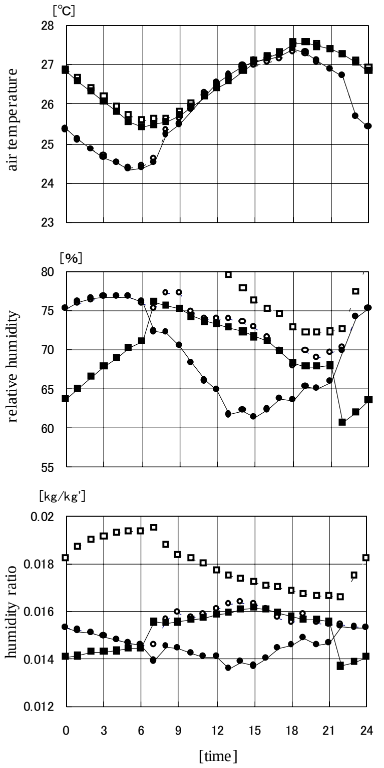


Figure 17 Thermal environment in case 2 (hothouse + cold water)

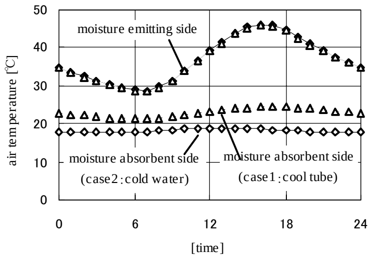


Figure 18 Changes in air temperature in the inlet

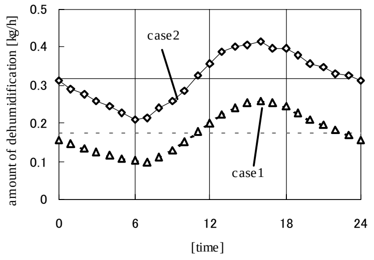


Figure 19 Changes in the amount of dehumidification

of each type of dehumidifier and relative humidity in the bedroom on the second floor at nighttime. Figure 11 shows the relation between the cooling load of each type of dehumidifier and humidity ratio, and Figure 12 shows the relation between cooling load and amount of dehumidification. The results showed that relative humidity in the bedroom of 60% can be achieved by the use of the standard type dehumidifier with a refrigerating capacity of 600W, the heat-recovery type dehumidifier with a refrigerating capacity of 400W, or the moisture-absorbent type dehumidifier with a refrigerating capacity of about 200W.

Figure 13 shows the relation between the cooling load of each type of dehumidifier and the amount of dehumidification throughout the day. At the same cooling load, the amount of dehumidification that can be obtained by the use of the moisture-absorbent type dehumidifier is about twice that from using the standard type dehumidifier and about 1.5-times greater than that from using the heat-recovery type dehumidifier. Thus, the moisture-absorbent type dehumidifier requires only half the refrigerating capacity of the standard type dehumidifier to achieve the same level of humidity.

Figures 14 and 15 show changes in the thermal environment when each type of dehumidifier is operated at what is thought to be its optimal refrigerating capacity (standard type : 600W, heat-recovery type-1 and type-2 : 500W, moisture-absorbent type-1 : 300W, moisture-absorbent type-2 : 200W). The temperature of supplied air in each of these cases are shown in Table 1. A suitable indoor climate can be obtained in all cases. However, in the case of the standard type dehumidifier, the difference in supplied air temperature must be reduced, because this difference causes condensation to form around the air diffuser, which can have adverse effects on the health of the inhabitants of the house. In the case of the heat-recovery type dehumidifier, although there is a greater improvement in the indoor thermal environment compared with that achieved by using the standard type dehumidifier, there is the possibility that condensation forms around the air diffuser in the bedroom at nighttime. In the case of the moisture-absorbent type dehumidifier, a comfortable level of humidity can be achieved in all rooms at a relatively small cooling load.

Moreover, if a heat source can be secured, dehumidification without the need for a refrigerator is possible in the case of the moisture-absorbent type dehumidifier. Figure 16 shows the thermal environment that can be obtained by using the moisture-absorbent type-1 dehumidifier in the case where a hothouse and a cool tube are used as the heat source (case 1), and Figure 17 shows the thermal environment that can be obtained by using the same dehumidifier in the case where a hothouse and cold water are used as the heat source (case 2). The hothouse faces south, has a ground area of 3.3m^2 and height of 2m, and contains 300 liters of water for heat storage. The cool tube is 20m in length, and the cold water is assumed to be 17 degrees centigrade. The air temperature in the inlet on the moisture emitting side is kept higher than 28 degree centigrade all day in the effect of the heat storage of water. Therefore, the hothouse is sufficient heat souce (Figure 16). In case 1, the amount of dehumidification is small because the air in the inlet on the moisture absorbent side is high (21.0 to 24.5 degrees centigrade) (Figures 18 and 19). In case 2, a sufficient amount of dehumidification can be obtained, and a better thermal environment can be achieved because the air in the inlet on the moisture absorbent side can be maintained in a lower temperature range (17.6 to 18.8 degrees centigrade).

CONCLUSION

In this study, improvements from the use of a dehumidifier to the indoor thermal environment of a house that has passive ventilation are investigated, and the performances of various types of dehumidifiers are also examined. It is found that a continuously suitable level of humidity can be obtained in all rooms at a relatively low cooling load by using a moisture-absorbent type dehumidifier rather than a standard type or heat-recovery type dehumidifier. Although air conditioners are currently used in most houses on hot days in summer, a moisture-absorbent type dehumidifier can also ensure the maintenance of a comfortable indoor environment at a lower energy or natral energy.

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