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A Hot-Water-Type Desiccant Ventilator Having Cool Air Supply and Dehumidification / Humidification Functions

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ABSTRACT

The demand for amenities such as an air conditioning system that regulates humidity in addition to temperature has been increasing in response to improvements in residential airtightness. To cater to these demands, a multifunctional residential-use desiccant ventilator unit that can be used all-day and year-round has been designed. This ventilator unit consists of two desiccant elements, two heat exchangers, a hot-water coil and two fans. Hot water generated from a gas cogeneration system or a gas boiler system is used as a heat source. The greatest feature of this unit is that it can supply cool air to residential spaces.

The principle behind our desiccant air-cooling system is as follows: (1) outside air is sufficiently dehumidified using the first and second desiccant elements that adsorb/desorb the humidity in the air, (2) the first desiccant element is revived by the dehumidified air (the humidity adsorbed by the element is vaporized), and (3) air-cooling is performed by using the heat of vaporization generated in step 2. Since this system performs air-cooling using the humidity in the air, it does not require the installation of additional components such as water piping and electric cooling devices. Although the outside air dehumidified by the first and second desiccant elements rises in temperature due to an exothermal reaction, it is cooled by another source of outside air in the first heat exchanger and by room air in second heat exchanger. The second desiccant element is regenerated by room air warmed in the hot-water coil. Besides supplying cool air, this ventilator has humidification and dehumidification functions.

In order to realize this design, we fabricated a residential-use prototype. The desiccant element is in the shape of a rotor consisting mainly of a polymer material that possesses high hygroscopicity and can dehumidify at low temperatures. This hygroscopic material based on a nano-controlled sodium polyacrylate (PAS) instead of conventional desiccants such as silica gel or zeolite was recently developed and used elsewhere. The heat exchangers are static-type sensible heat exchangers formed of corrugated aluminum plates. The size of the prepared heat exchanger was selected such that a temperature exchange rate of 70 to 80% can be achieved at an air capacity of 120 m^3/h. The performance of the prototype unit was measured in a constant-temperature and constant-humidity test room controlled to a summer environment: outside air temperature of 28-35 °C, outside air humidity of 40-70% RH, room air temperature of 26-32 °C, room air humidity of 50 %RH, ventilation volume of 120 m^3/h, and a hot water temperature of 75 °C.

The test results show that the prototype unit can supply a flow having a temperature 8-12 °C lower than that of outside air. The temperature of the supply air depends on the absolute humidity of outside air because the amount of moisture absorbed or desorbed by the desiccant rotor for cooling increases with the absolute humidity of the outside air. As a result, the cooling characteristics of the supply air are enhanced.

Introduction

With the growing focus on saving energy, the general needs for air tightness and heat insulation in houses have increased progressively. Therefore, the installation of mechanical ventilation systems to replace room air with outside air is becoming indispensable. To decrease the air-conditioning load due to the introduction of outside air as much as possible, ventilators are expected to be equipped with a mechanism to control the temperature and humidity of the introduced outside air.

Desiccant ventilation units with the desiccant element comprised of water adsorption/desorption materials are a type of system capable of meeting the need of humidity control. These units can humidify or dehumidify the process air by using heat as a driving source. For example, during the hot and humid summer season in Japan, the unit can decrease the air-conditioning load by supplying outside air with decreased humidity. In addition, by humidifying the room in the dry winter season, the merits of increased sensible temperature and decreased air-conditioning temperature are attained.

We have developed a desiccant ventilation unit with a temperature control function in addition to the conventional humidity control function. Its greatest feature is the capability of supplying cold air by the use of only warm water at a temperature of 60 to 80 °C, which is obtained by heating the water with a gas boiler or using the waste hot water of a household gas cogeneration system. Because this unit has both a cold air supply function and the conventional humidification/dehumidification functions, it can be used year-round.

Desiccant Air-Cooling System

The principle behind our desiccant air-cooling system is depicted in Figure 1 with details that are as follows: (1) outside air is sufficiently dehumidified using the first and second desiccant elements that adsorb/desorb the humidity in the air, (2) the first desiccant element is revived by the dehumidified air (the humidity adsorbed by the element is vaporized), and (3) air-cooling is performed by using the heat of vaporization generated in step 2. Since this system performs air-cooling using the humidity in the air, it does not require the installation of additional components such as water piping and electric cooling devices. Besides supplying cool air, this ventilator has humidification and dehumidification functions.

Although outside air dehumidified by the first and second desiccant elements rises in temperature due to an exothermal reaction, it is cooled by another source of outside air in the first heat exchanger and by room air in the second heat exchanger. The second desiccant element is regenerated by room air warmed in the hot-water coil. The theoretical psychrometric diagram of the abovementioned cycle of outside air is shown in Figure 2, where the following conditions are applied: outside air temperature and humidity of 35 °C and 50% RH, room air temperature and humidity of 28 °C and 50% RH, respectively, and temperature exchange rate of the heat exchangers of 80%.

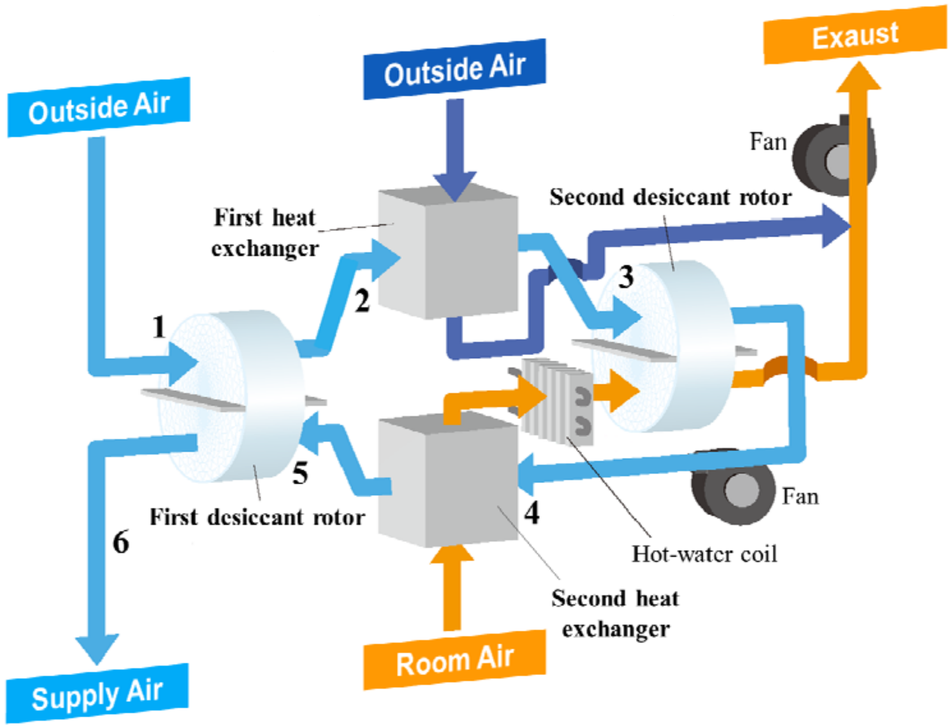

Fig. 1 Desiccant air cooling system

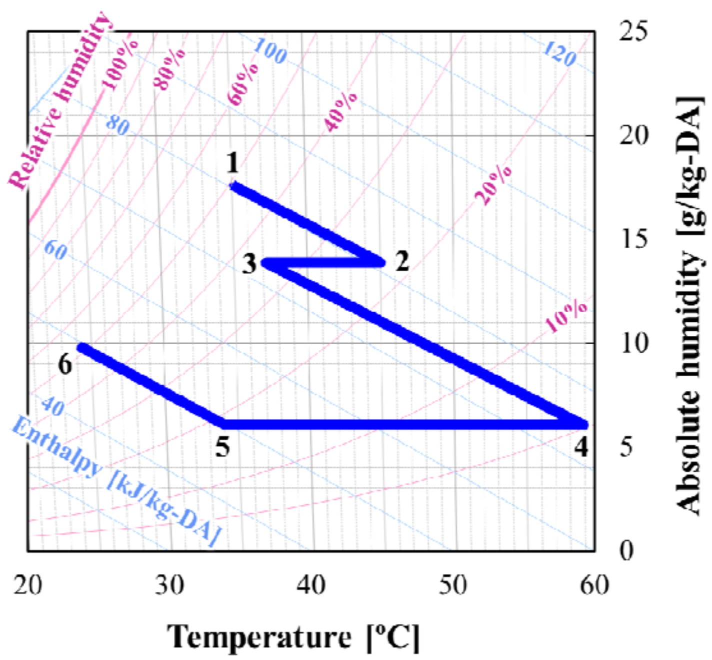

Fig. 2 Psychrometric diagram of desiccant air-cooling system

Experiment

In order to realize this design, we fabricated a residential-use prototype. The desiccant element is in the shape of a rotor consisting mainly of a polymer material that possesses high hygroscopicity and can dehumidify at low temperatures (Figure 3). This hygroscopic material based on a nano-controlled sodium polyacrylate (PAS) series of water-absorbing polymers instead of conventional desiccants such as silica gel or zeolite was recently developed and used elsewhere[1)]. The material can be rivived at low temperatures (60-80 °C). Thus, a ventilator unit can be built that uses the hot water exhausted from a gas cogeneration system or a gas boiler system as the heat source.

We assembled the prototype unit using the following components: two PAS desiccant rotors, two heat exchangers, a hot-water coil, and three fans. Figure 4 shows the appearance of the prototype. The desiccant rotors are 75 mm thick and 210 mm in diameter, and built from a cell with a height of 1.2 mm and a pitch of 2.4 mm. The heat exchangers are static-type sensible heat exchangers formed of corrugated aluminum plates. The size of the prepared heat exchanger was selected such that a temperature exchange rate of 70-80% can be achieved at an air capacity of 120 m^3/h.

1) Basic performance testing

The performance of the prototype unit was measured in a constant-temperature and constant-humidity test room controlled to a summer environment: outside air temperature of 28-35 °C, outside air humidity of 40-70% RH, room air temperature of 26-32 °C, room air humidity of 50% RH, ventilation volume of 120 m^3/h, and a hot water temperature of 75 °C. The flow rate, temperature, and humidity of the test air and regeneration air were measured using flow meters and temperature-humidity sensors (ETO-DENKI 2119A), respectively. The desiccant rotor was designed to revolve at a constant speed with the help of an inverter motor. The outside air and room air were supplied using air generators (ORION AP-750MVP) that could regulate temperature and humidity

Fig. 3 Picture of PAS desiccant rotor

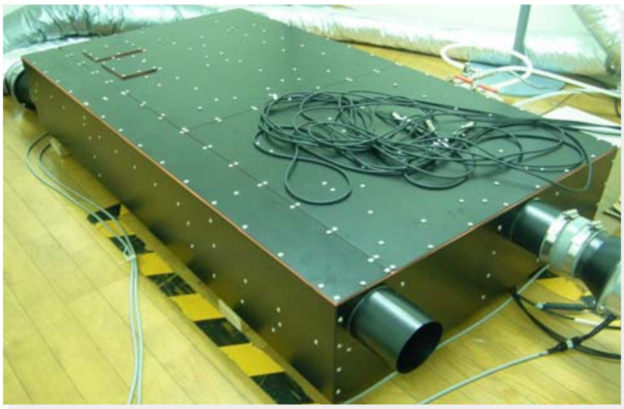

Fig. 4 Prototype of desiccant ventilator unit

2) Actual environment testing

During the summer, we installed and operated the prototype in an experimental house and evaluated the effect of its operation on the indoor environment. The ventilation air flow was adjusted to 36 m^3/h for a 30 m^2 room (a volume of 72 m^3). Warm water heated by a gas boiler (approximately 75 °C) was used as the heat source. The temperature and humidity in the room were measured by temperature-humidity sensors (ETO-DENKI 2119A). During the operation of the prototype, the room was cooled down to 28 °C by running an air conditioner for two hours, after which the room air conditioner was turned off. Thereafter, the time change of temperature and humidity were measured.

Results and Discussions

Figure 5 shows the relationship between the cold air supply performance and outside air temperature from the basic performance test. From this figure, we observe that at an outside air humidity of 60% RH, which is close to the average summer humidity in Japan, air with a temperature lower by 8 to 12 °C than that of the outside air can be obtained. Further, the higher the outside air temperature and relative humidity, the greater the cooling performance. This suggests that the cooling performance depends on the absolute humidity of the outside air. As shown in Fig. 1, the process that most contributes to the cold air supply is the endothermic reaction of the moisture desorbed by the first rotor. Because the amount of heat absorbed increases with the amount of moisture desorbed, the air supply temperature decreases. In other words, the higher the absolute humidity of the outside air, the larger the amount of moisture adsorbed to /desorbed by the first rotor. Therefore, the air supply temperature is decreased. Figure 6 shows the relationship between the supply air temperature and room air temperature. It indicates that the prototype unit can supply air with a temperature 2 to 3 °C lower than the room air temperature.

Figure 7 shows the results of the actual environmental test conducted at night, when there is no solar radiation. Despite the fact that the difference in the temperature between the room and the outside air was approximately 5 °C, the room temperature was able to be maintained at 26–28 °C for more than 12 hours. It was also demonstrated that although the relative humidity of the outside air reached 70% RH, the relative humidity in the room was maintained at approximately 45–60% RH.

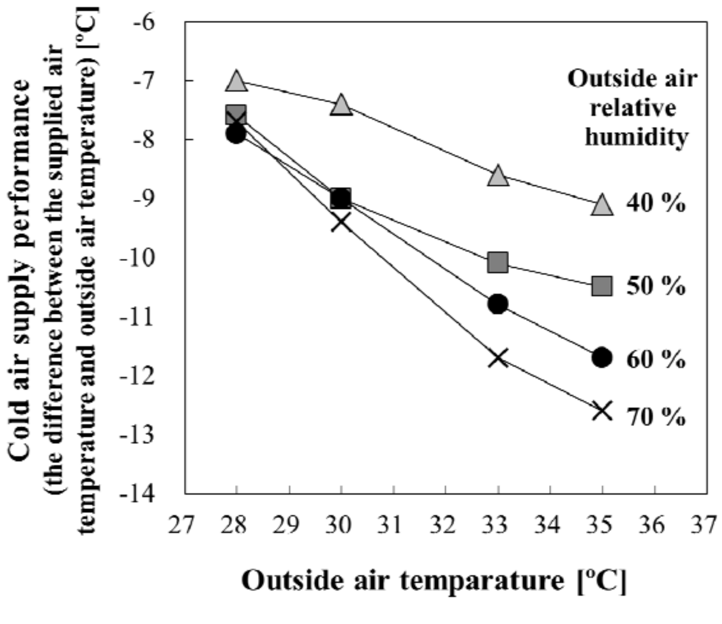

Fig.5 Effect of temperature of outside air on temperature of supply air
(Room air is controlled to temperature of 26 °C and humidity of 50% RH.)

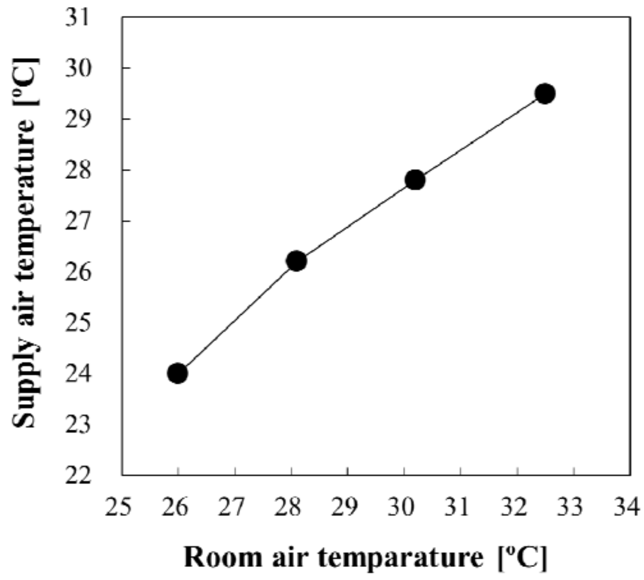

Fig.6 Effect of temperature of room air on temperature of supply air
(Outside air is controlled to temperature of 34 °C and relative humidity of 50% RH.
Room air is controlled to humidity of 50% RH.)

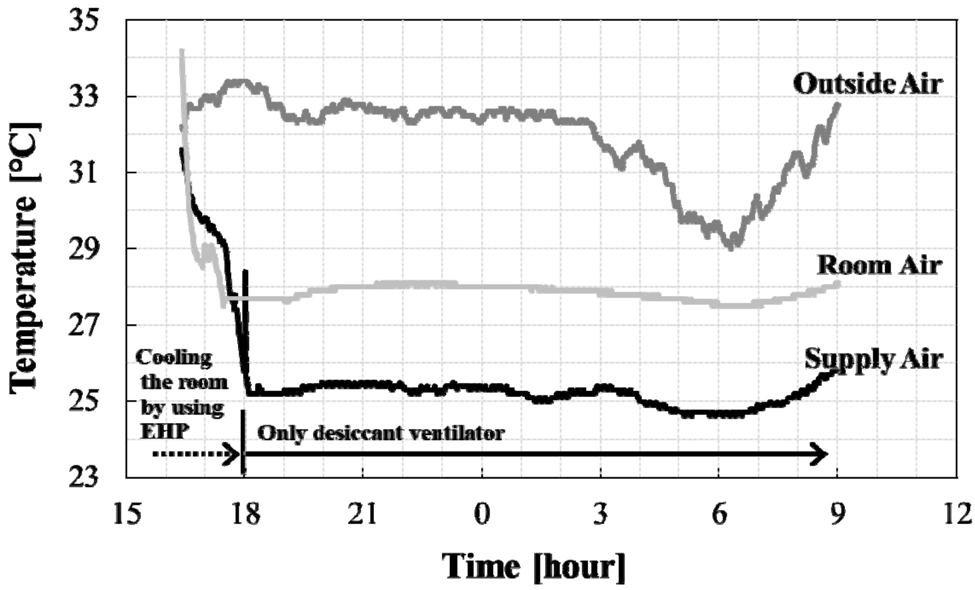

Fig.7 The time change of room temperature in the experimental house during the night on a summer day when the prototype unit was operated

Conclusions

We designed a desiccant system that can supply cold air and be used as a new residential ventilation system. In this system, hot water heated by a gas is used. We conducted a prototype performance test, and our results demonstrate that the system can supply cold air and reduce air-conditioning load in the summer by cooling and dehumidifying outside air.

Reference

1) Inaba, H., T. Kida, A. Horibe and J. Kaneda; "Sorption Characteristics of Honeycomb Type Sorption Element Composed of Organic Sorbent," Transactions of the Japan Society of Mechanical Engineers, 66, B, 164-171 (2000)