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メンブレンを用いる除湿機構の従来空調システムへの応用

Application of Dehumidification system Using Membrane for Conventional HVAC system

C. 環境工学　4. 環境工学　9. 湿気

Membrane　Dehumidification　Laten Heat Load
Conventional HVAC

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1. Introduction

Last year, the Japanese government set an ambitious goal of achieving carbon neutrality by 2050. In order to achieve this goal, the government has been making multifaceted efforts, including the announcement of a growth strategy. The Green Growth Strategy defines 14 growth sectors as part of the industrial policy to create a virtuous cycle between the economy and the environment, and presents the current status, challenges, and future policy support. One of the 14 growth areas is the housing and building industry and the next-generation solar industry, which refers to the policy of promoting zero energy buildings. This is expected to accelerate the spread of zero energy buildings.

The realization of zero energy buildings must be accompanied by maximum energy conservation and the use of renewable energy sources. Recent studies show that the heat load of buildings is decreasing due to the ultimate energy-saving efforts to achieve zero energy, and its properties are expected to change. Noteworthy in the change in heat load profiles is the decrease in sensible heat ratio due to the current decrease in heat load, but the dehumidification dysfunction caused by this has been recognized as a problem affecting the indoor thermal environment (G. Yoon, 2017).

As a countermeasure to this problem, developing and applying efficient dehumidification mechanisms in the design of air conditioning systems is a necessary reality. Conventional condensing-cooling methods are recognized as indoor thermal environment hindrances due to the increase of reheat energy and the decrease of dehumidification capacity in accordance with the decline of sensible heat ratio. Therefore, an alternative efficient dehumidification method is an urgent reality. The technological development of alternative dehumidification methods using desiccants and membranes has become more and more active. Therefore, the author is focusing on the membrane-based method.

The membrane system uses a moisture separation membrane to separate the moisture in the conditioned air. Unlike the desiccant system, the membrane system does not require a regenerative heat source, and its relatively simple system is attracting attention as an alternative technology to conventional dehumidification systems. Cho (H. Cho, 2021) constructed a test device and developed a numerical model. The energy efficiency of this dehumidification system was evaluated and compared with the conventional system. Compared to the conventional dehumidification system, the improved energy saving performance was confirmed in terms of the elimination of the overcooling and reheating process. On the other hand, depending on some conditions, the improvement is relatively small, suggesting development issues such as efficient control of the vacuum pump. Thus, the membrane method is a technology that is still under development, and it is expected to take some time before it becomes commercially available. Therefore, a realistic alternative is to seek complementary applications to supplement the dehumidification function of conventional air conditioning systems by using the performance and functions that can be achieved at present. However, most of the related research and development to date has been focused on studying the feasibility of the system and evaluating its energy efficiency, and most of them have pursued the function and performance of completely replacing the conventional dehumidification system while following the design strategy of the conventional air conditioning system.

Therefore, the purpose of this study is to understand the

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performance and functions that can be achieved with membrane systems at this point , and to propose a design strategy that can be applied to conventional air conditioning systems as an supplementary measure, as well as to review the air conditioning system design itself and present an optimized design strategy suitable for membrane application. This will not only improve the dehumidification insufficiency of conventional air-conditioning systems, but also promote the development of membrane technology and enable the accumulation of technology that will shorten the time to commercialization.

2. Application of Membrane Dehumidification System

In order to demonstrate the proposed application of the membrane system, the design conditions during cooling operation were set as follows. Assuming that the design outdoor air volume during cooling operation is set to 4.5 m^3/m^2h, the room peak cooling load is 78.6 W/m^2, and the sensible heat load is 56.6 W/m^2, the sensible heat factor becomes 0.72. At this time, assuming that the air supply temperature is 15 °C, the design air supply air volume is 15.6 m^3/m^2h.

2.1 Improving Dehumidification capability for Existing AHU System

Figure 1 shows the process improving the dehumidification capability by using the membrane for the existing Air handling unit (AHU) of which dehumidification performance has been declining in recent years as the sensible heat ratio of the indoor load has decreased. Table 1 shows the comparison of each heat treatment rate as well. The case-0 in the figure shows the conditioned air diagram of the existing air conditioner, and it can be confirmed that reheat is required by setting the supply air temperature to 13 °C. It can be seen that the required supply air temperature and humidity can be achieved without the reheating process if a membrane is introduced to dehumidify the conditioned air, as in case-2. In this case, the required dehumidification amount is 74.9 g/kg'.

On the other hand, if the supply air temperature of the existing air conditioner is set to 15 °C and the membrane is used to dehumidify the air to achieve the required supply air temperature and humidity as in case-1, the required dehumidification amount of the membrane is 18.7 g/kg', which is about 75% less. In this way, when membranes are used to supplement existing air conditioners, the deployment of membranes can be reduced in scale.

2.2 Compensating dehumidification for DOAHU

Figure 2 shows the process assuming the supplementary measures for the dehumidification function of Dedicated Outddor Air Handling Unit (DOAHU). Table 2 shows a comparison of the heat rates of each process. It can be assume assumed that the supply air temperature of DOAHU is usually

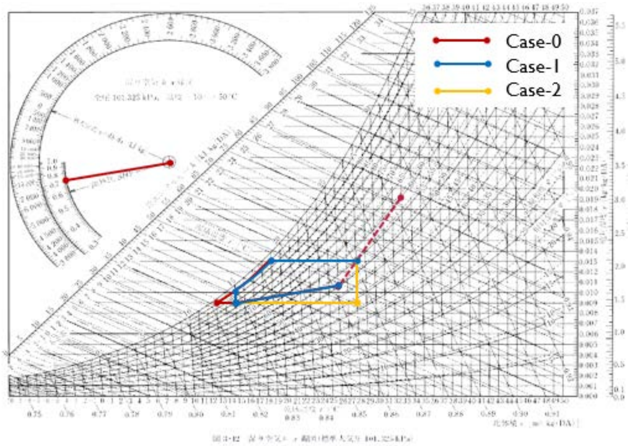

Figure-1 Avoiding Reheat Progress and Complement dehumidification

Table-1 Treated Heat Rate for each Case

	Case-0	Case-1	Case-2
Supply Air Volume [m^3/hm^2]	15.6	15.6	15.6
Cooling Heat Rate [W/m^2]	130.0	106.6	66.9
Reheating Rate [W/m^2]	10.3	-	-
Dehumidification Amount [g/kg'm^2]	-	18.7	74.9
Treated Latent Heat Rate [W/m^2]	-	13.1	52.4
Total Heat Rate [W/m^2]	140.3	119.7	119.3

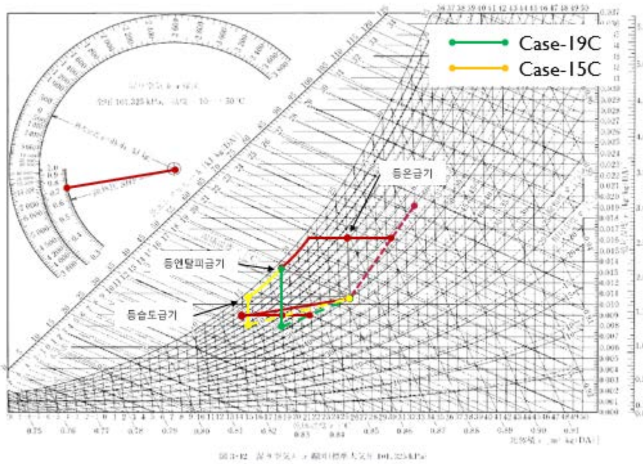

Figure-2 Compensating Measure for DOAHU

Table-2 Treated Heat Rate for each Case

	Case-19C	Case-15C
Supply Air Volume [m^3/hm^2]	4.5	4.5
Cooling Heat Rate [W/m^2]	30.0	45.0
Reheating Rate [W/m^2]	-	-
Dehumidification Amount [g/kg'm^2]	29.7	16.2
Treated Latent Heat Rate [W/m^2]	20.8	11.3
Total Heat Rate [W/m^2]	50.8	56.3

iso-enthalpy supply air (design supply air temperature: 19°C) or iso-humidity supply air (design supply air temperature: 15°C). At this time, considering the fact that the sensible heat ratio of the indoor heat load tends to decrease, as lower as the air supply temperature would be better. However, setting a low air supply temperature for DOAHU will cause in overcooling at low heat loads. If a membrane is applied to this, the supply air temperature setting of DOAHU can be higher, and the overcooling could be mitigated. When the supply air temperature is set at 19 °C and 15 °C, the required dehumidification amount with the membrane is 29.7 g/kg' and 16.2 g/kg' respectively. Although the required dehumidification amount of the membrane increases by the relatively high supply air setting temperature of DOAHU, it may have a ripple effect on the energy saving of heat source equipment because the chilled water temperature of HVAC system can be made higher.

2.3 Getting Higher Temparature of Supply Air and Chilled Water

In conventional air cooling systems that are based on condensing cooling, the design supply air temperature of the cooling system is around 15 °C. However, it is need no more to set 15 °C using a membrane eliminates. It is desirable to review the design air supply temperature itself and set it in response to the recent problem of decreasing the sensible heat ratio. the design air supply volume will be 15.6 m^3/hm^2 when the temperature is set to 15 °C, and 21.4 m^3/hm^2 when the temperature is set to 18 °C, an increase air volume of about 37.2%. By using the membrane to set the air supply design temperature higher at 18 °C, the increasing supply air volume could improve the indoor ventilation efficiency. In addition, the increase in the airflow rate will induce an increase in the air velocity sucked into the membrane, which can be expected to improve the dehumidification efficiency. Furthermore, the chilled water temprature be raised to a higher, then the heat source equipment can be operated more efficiently.

3. Subjected Membrane Sysmtem

3.1 System Configuration and Outline

A gas separation membrane dehumidification system based on a vacuum pump consists of a hollow fiber membrane and a vacuum pump, as shown in Figure-4. In the membrane dehumidification system, moisture is permeated by the water vapor partial pressure difference between the permeable membranes, and the water vapor partial pressure difference is formed using a vacuum pump. The dehumidification capacity and energy performance of this system depends on the intake air temperature, absolute humidity, airflow rate, and vacuum pump pressure and membrane selectivity.

3.2 Evaluation of System Performance

An air conditioning system was assumed under the conditions of a typical office space. The dehumidification per-

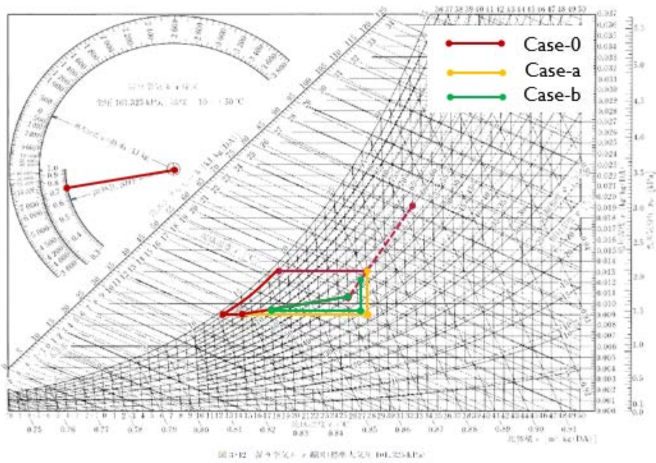

Figure-3 Application of Higher Supply Air Temperature

Table-3 Treated Heat Rate for each Case

	Case-0	Case-a	Case-b
Supply Air Volume [m^3/hm^2]	15.6	15.6	21.4
Cooling Heat Rate [W/m^2]	130.0	66.9	67.0
Reheating Rate [W/m^2]	10.3	-	-
Dehumidification Amount [$g/kg'm^2$]	-	74.9	74.5
Treated Latent Heat Rate [W/m^2]	-	52.4	52.1
Total Heat Rate [W/m^2]	140.3	119.3	119.2

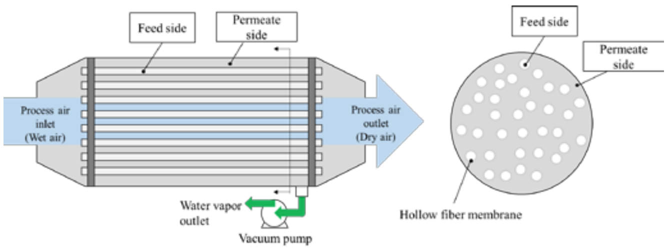

Figure-4 System diagram of Vacuum Pump based Membrane Dehumidification

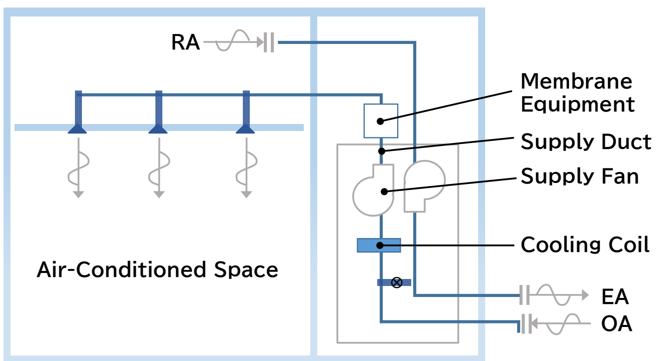

Figure-5 Conventional HVAC system with Membrane formance of the membrane system was evaluated by numerical simulation. The design airflow rate of the air conditioner was designed to be 4,600 m^3/h, and the cooling coil capacity was set to 49.3 kW. The membrane was installed at the outlet of the cooling coil of the air conditioner to dehumidify the air supplied by the air conditioner, and the dehumidification setting absolute humidity was set to 8 g/kg'.

The room air temperature and humidity were set at 26°C and 50%, and the air conditioning time was from 8 am to 9 pm. The room was set to have low internal heat gain in order to reproduce the situation of low sensible heat factor in the room.

Figure-6 shows the simulation results. Due to the setting of low internal heat gain in the room, the air conditioner was supplied with the minimum airflow rate of 3,000 m^3/h, and the supply air temperature increased to about 22°C according to the room load. First of all, the absolute humidity of the air supply for the case without membrane shows that it was supplied at about 16 g/kg'. In contrast, it was confirmed that the introduction of the membrane lowered the supply air humidity as seen in the figure. When the 5 kW vacuum pump was used, the supply air humidity was about 12 g/kg', which was higher than the setting humidity of 8 g/kg'. It can be seen that the required capacity of the vacuum pump exceeds 5 kW and the reduction range of the air supply humidity is constant. In the case of 20 kW vacuum pump used, the reduction range is larger, and it can be seen that the set humidity of 8 g/kg' is achieved and kept constant.

Figure-7 shows the electric power consumption of the vacuum pump for each case. It can be seen that in the case of the 5 kW vacuum pump, the power consumption is kept constant at the rated power consumption of 5 kW, and in the case of the 20 kW vacuum pump, it fluctuates depending on the amount of dehumidification.

The COP was calculated as the amount of dehumidification to the unit vacuum pump consumption. The case with 5 kW vacuum pump showed a maximum of 1.92, and the daily average COP was 1.75. In the case of 20 kW vacuum pump, the daily average COP was 1.44, which was lower than that of the 5 kW case.

Table-4 shows the total daily dehumidification and vacuum pump consumption for the day under study. The total daily dehumidification of the 5 kW case was 265.4 kg, which was about 43% less than that of the 20 kW case. On the other hand, the daily consumption was 70 kWh, showing 55% less

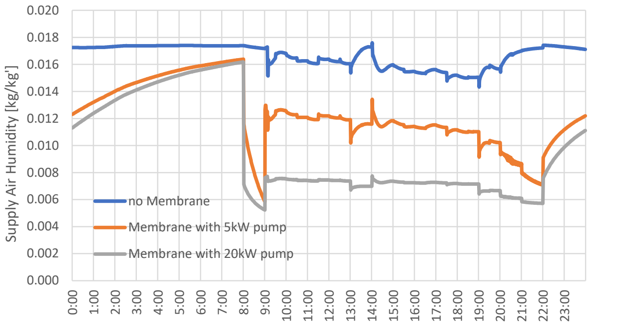

Figure-6 Absolute Humidity of Supply air for Each Case

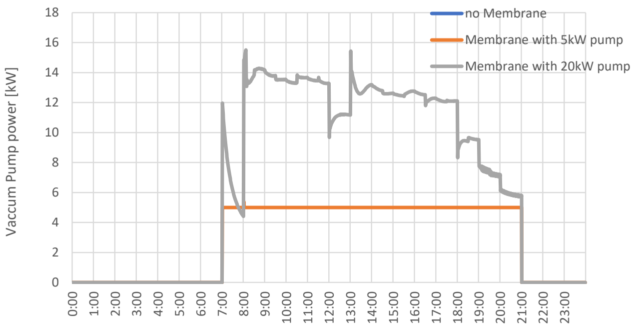

Figure-7 Electric Power Consumption for Vacuum Pump

Table-4 Dehumidification per Electric Power Consumption

Rated Vacuum Pump Power	Daily dehumidification [kg]	Daily Electric power Consumption [kWh]	Dehumidification per Electric Power [kg/kWh]
5kW	265.4	70.0	3.8
20kW	465.1	158.1	2.9

The unit dehumidification of the 5 kW case was 3.8 kg/kWh, and that of the 20 kW case was 2.9 kg/kWh, with the 5 kW case showing 31% more than the 20 kW case in terms of unit dehumidification.

4. Conclusions

As the needs for advanced dehumidification systems have been increasing in recent years, the membrane dehumidification system is one of the technologies that are attracting attention. In this paper, the application to conventional air conditioning systems and the concept of system design based on the use of membranes are proposed.

REFERENCES

G. Yoon, Heat load profile for ZEB and requirements for heat pump technology, Heat Pumping Technologies Magazine, 35(3), pp.27-30, Feb. 2017

H. Cho, S. Cheon, J. Jeong, Energy impact of vacuum-based membrane dehumidification in building air-conditioning applications, Appleid Thermal Engineering, 182(2021) 116094