Experimental Evaluation Study of The HVAC System with Temperature and Humidity Independent Control Using Separate Type Air Conditioners

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Abstract: The energy requirements for air conditioning equate to approximately 40% of the total energy consumption of commercial buildings. To achieve a net Zero Energy Building (ZEB), the reduction of energy consumption for air conditioning is essential. To reduce the consumption of energy for air conditioning, the temperature and humidity individual control (THIC) system is a very effective means. In this paper, the THIC system consisted of a humidity controllable outer air processing unit (heat pump desiccant) and a sensible capacity enhanced VRF installed for the demonstration test. The test results showed that the THIC system can reduce energy consumption by approximately 50% in midsummer, and 30% in midwinter. The data also made it possible to develop a simulation to calculate the THIC system's energy consumption. The simulation showed that the THIC system can reduce the energy consumption by 74% in the case that the system is installed in highly insulated buildings and operated all throughout the year.

Key Words: heat pumps, VRF, temperature and humidity individual control

1 INTRODUCTION

The reduction of Green House Gas emissions is one of the most important challenges globally. GHG emission from commercial buildings is up to almost 20% of the total amount in Japan. Therefore, the energy-conservation standard to restrict the primary energy consumption of commercial buildings was established, and more a stringent standard called the ZEB standard is under consideration. Moreover, the value of energy conservation intensified following the Japanese 3.11 tsunami disaster due to the closure of the nuclear power plants and subsequent lack of electricity. Therefore, commercial air conditioning and heat pumping systems, which consume about 50% of the electricity in office buildings (Huang et al., 2006; Zhou et al., 2007) require that their energy consumption significantly reduced.

To achieve a drastic reduction of air conditioning energy consumption, one of the most effective solutions is a system that controls both “Temperature” and “Humidity” via individual mechanisms to each set value (THIC system). The effectiveness of the THIC system with specially developed air-conditioning and ventilating machines will be discussed in this paper.

2 EFFECTIVENESS OF THE THIC SYSTEM

To drastically reduce air-conditioning energy consumption, the adoption of the THIC system is effective for the reduction of the air-conditioning load itself. The THIC system enables us to reduce the air-conditioning load for the following two effects.

One is to avoid over-dehumidification. In the case that the latent heat load and sensible heat load are treated by one mechanism, the amount of latent heat capacity is decided along with the sensible heat capacity. Therefore, if the sensible heat load is relatively high compared to the latent heat load, the mechanism will treat too much of the latent heat, and it will cause unnecessary energy consumption as is illustrated in Figure 1 below.

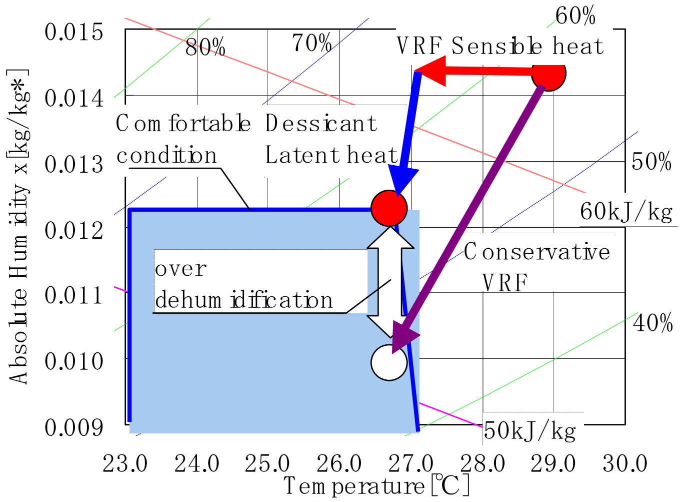


Figure 1: Avoidance of Over Dehumidification

The other effect for heat load reduction is from the tolerance of inner air condition. As shown in Fig.2, if the sensible heat load is relatively low compared to the latent heat load, the mechanism will treat too less of the latent heat, and it will cause an uncomfortable inner air condition as is illustrated in Figure 2 below.

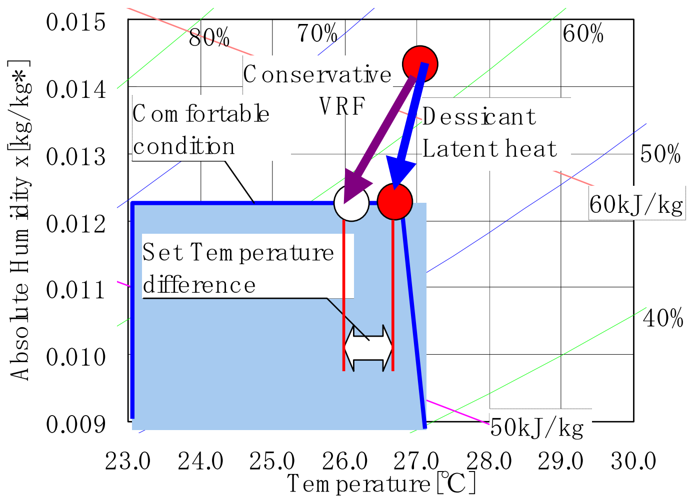
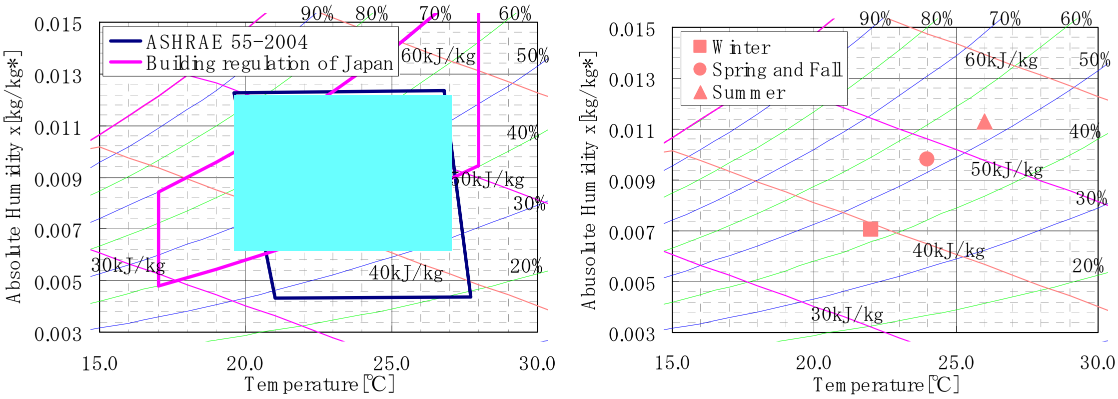


Figure 2: Adequate Dehumidification Achievement with Higher Set Temperature

To avoid that situation, the set temperature of the room is commonly set lower in advance. Alternatively, the residents will feel the air to be damp and hot even if the set temperature is fulfilled, and they will re-set the temperature lower. In the case of heating operation, the lack of humidity derived from the only temperature control will cause the residents to feel cold, and the set temperature will be raised. Therefore, the adoption of the THIC system enables us to tolerate wider inner air conditions, and reduce the air-conditioning load. The comparison of the adaptable inner air conditions are shown in Figure 3 as below.



For Temperature and Humidity Individual Control Previous

Figure 3 : Difference of Inner Air Condition

3 COMPOSITION OF THE THIC SYSTEM

In this paper, the THIC system consisted of the humidity controllable outer-air processing unit (HP desiccant) which mainly treats the latent heat load; and sensible capacity enhanced VRF, which mainly treats the sensible heat load. These two mechanisms are appropriately operated by the controller to simultaneously maintain the comfort of the room and save energy. The system composition is shown in Figure 4 as below.

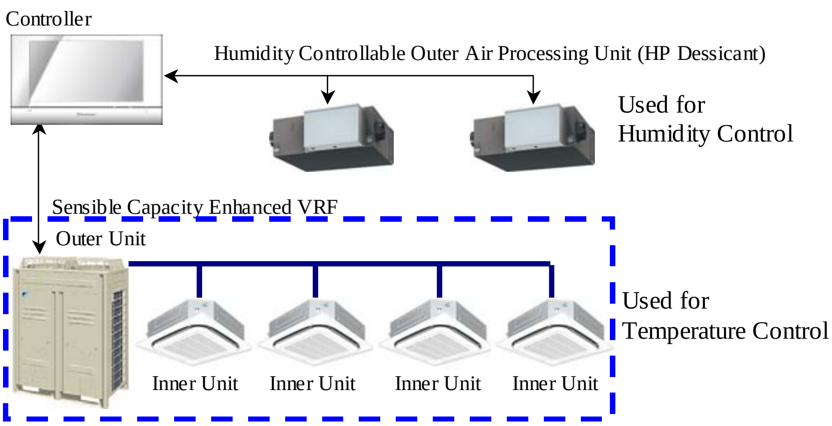


Figure 4 : Composition of Temperature and Humidity Individual Control System

The direct expansion VRF system consumes less energy for heat transfer compared to the central type air conditioner. Moreover, the VRF can avoid heat loss from the connection piping in cooling operation. So, the VRF system is more suitable for significantly reducing energy consumption.

2.1 Features of HP Desiccant

There are several systems available for humidity control. One of the widely prevailing ways to be adopted for office buildings is the desiccant wheels. The desiccant wheels repeatedly adsorb and desorb the moisture. The desiccant's adsorption is an exothermal reaction, and desorption is an endothermal reaction. In the desiccant wheel operation, the heat needed for the desorption phase has to be supplied by heating the air previously flowing into the wheel. Consequently, the temperature needed to heat the air is very high (60degC to 80degC) as shown in Figure 5. To achieve such a high temperature heat source, we have to use either exhaust heat, boiler, or a furnace. Unfortunately, the exhaust heat source does not universally exist. Furthermore, if the boiler or furnace is used as a heat source, the efficiency is reduced.

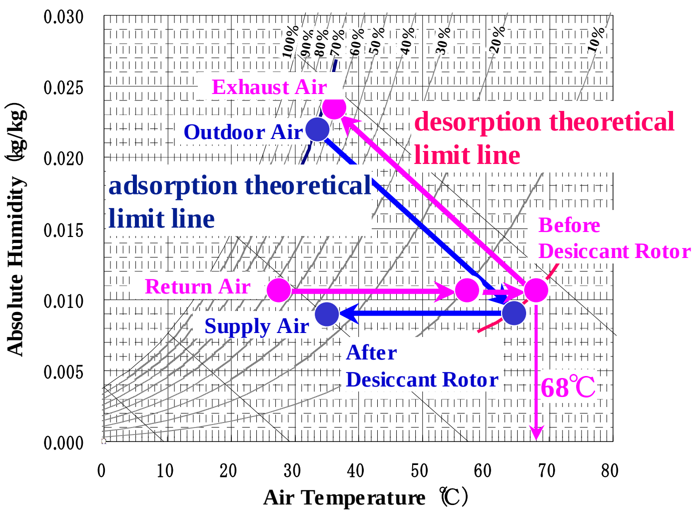


Figure 5 : Psychrometric Chart of Conventional Desiccant System

To achieve a drastic reduction of energy consumption, an efficient humidity control mechanism is needed. In the THIC system, the humidity controllable outer-air processing unit (HP desiccant) is adopted.

The most important feature of HP desiccant is using the Hybrid Desica Element (HDE) which is a heat exchanger covered with desiccant material (shown in Figure 6 below). By using HDE, the heat needed for desorption can be supplied directly on to the desiccant materials, and so the required temperature for desorption becomes as low as 40degC to 50degC as shown in Figure 7 below.

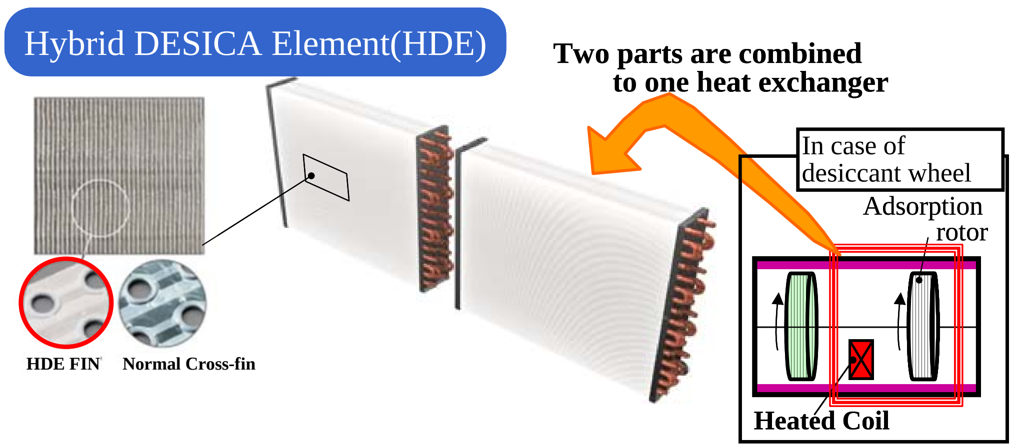


Figure 6 : Hybrid DESICA Element

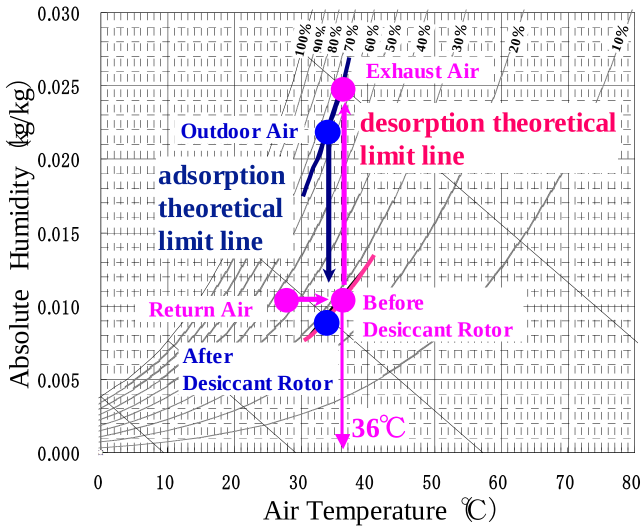


Figure 7 : Psychrometric Chart of HP Desiccant System

By lowering the required temperature for desorption, a heat pump can be used for the desorption process. A heat pump can transfer the heat from the adsorption process to the desorption process, and that drastically improves the efficiency of HP desiccant. In HP desiccant, two HDEs are operated in batch processing (alternately adsorbing and desorbing the desiccant material).
The HP desiccant with especially higher efficiency is used for the THIC system. The optimization of the heat exchanger path arrangement equalizes temperature of the HDE's surface, and improves efficiency.

2.2 Features of the sensible capacity enhanced VRF

To raise the efficiency of the heat pump, one of the most suitable ways is to reduce the pressure difference between the condensing temperature and the evaporative temperature. In the case of the cooling operation, when the air-conditioning load is less, the evaporative temperature can be raised. In the case that the ambient air temperature is low, the condensing temperature can be lowered (shown in Figure 8 below).

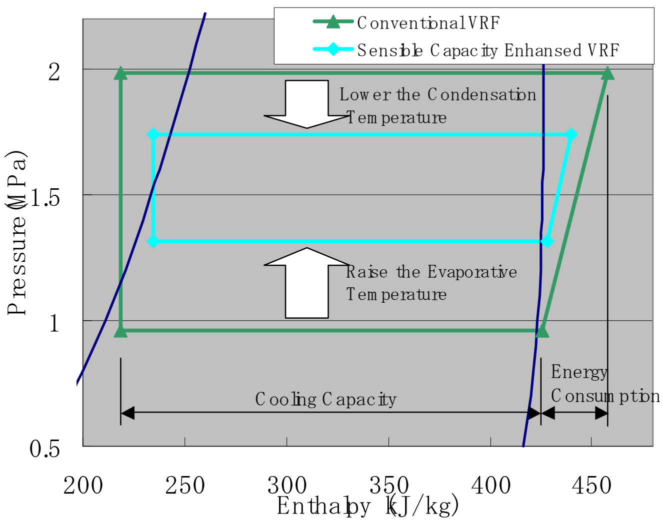


Figure 8 : Mollier Chart of Conventional and Sensible Capacity Enhanced VRF

However, the improvement of efficiency by the reduction of the pressure difference has not been common in the conventional VRF.

One of the reasons that prohibit the reduction of pressure difference is the necessity of the dehumidifying capacity. In the case that the cooling load is small, VRF can be operated with the higher evaporative temperature to fulfill the sensible heat load. But, that makes the latent heat capacity of VRF low at the same time (shown in Figure 9 below), and that may make the room air too damp.
In the THIC system, the latent heat load is treated by HP desiccant. So, the VRF can be operated in higher evaporative temperatures according to the sensible heat load.

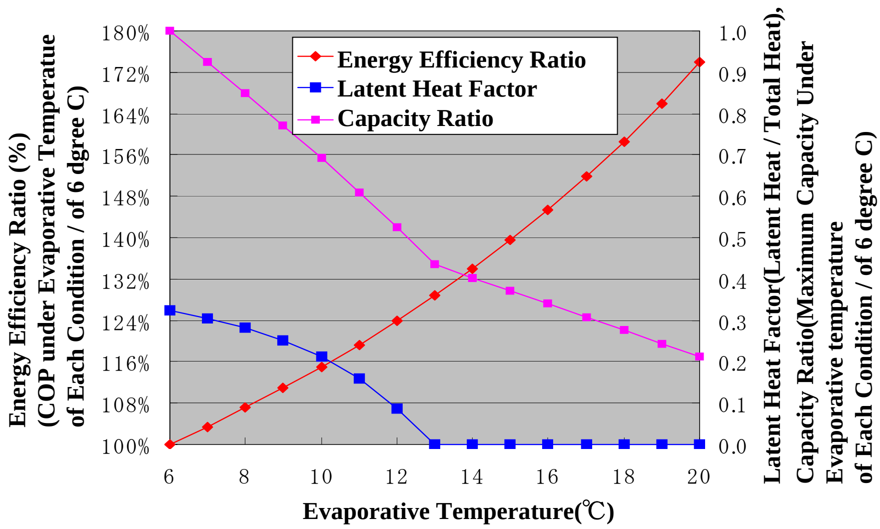


Figure 9: Evaporative Temperature's Effect to the VRF system

The other reason is the limitation of the compressors' operation. Scroll compressors are commonly used for VRF. In scroll compressors, the orbiting scroll is pressed against the fixed scroll by the pressure difference between high-and-low gas pressures, so that leakage in scroll is reduced. If the pressure difference is small, leakage loss increases, and that makes the efficiency of compressor worse.

We developed a new scroll compressor which is far more tolerant for the operation with the small pressure difference operation (shown in Figure 10 below), which makes it possible to drastically reduce the pressure difference.

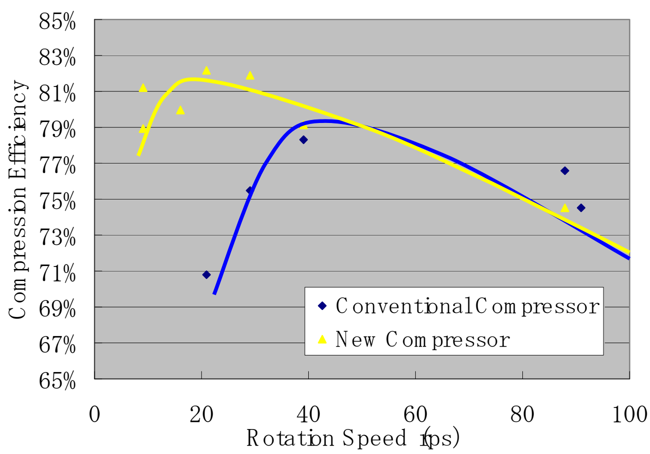


Figure 10 : Comparison of Compressor Efficiency

In this way, the sensible capacity enhanced VRF for the THIC system can be operated in smaller pressure difference, and that improves the efficiency under the condition of lower ambient temperature and smaller sensible heat load drastically as shown in Figure 11.

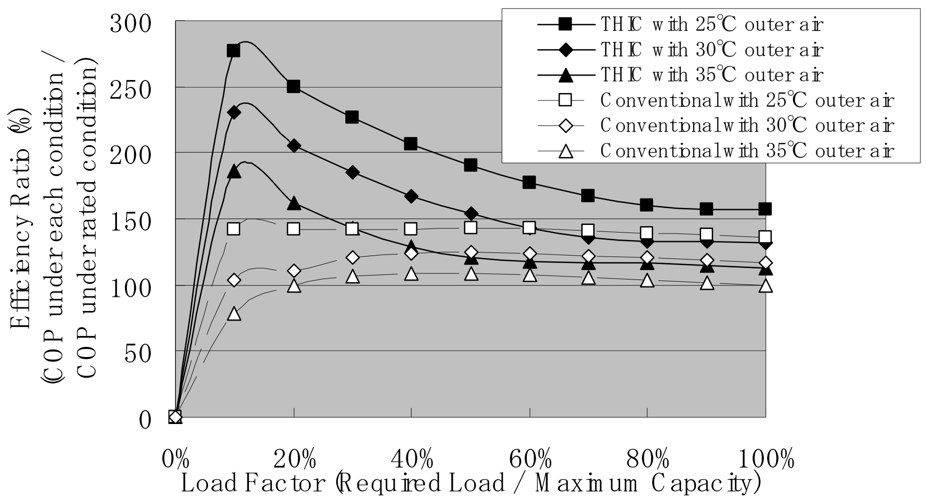


Figure 11 : Comparison of VRF Efficiency

Moreover, to reduce the standby power requirement, the optimized control of the crank case heater of the compressors is adopted for the sensible capacity enhanced VRF.

4 RESULT OF DEMONSTRATION TEST

The demonstration test was carried out to assure the effectiveness of the developed THIC system. The test was conducted in cooperative with Nagoya University and Nikken Sekkei Research Institute, under the subsidy of NEDO (New Energy and Industrial Technology Development Organization).

The test site was the office in Nagoya University. We used one room separated into two for the comparison of the conventional system and the THIC system as shown in Figure 12.

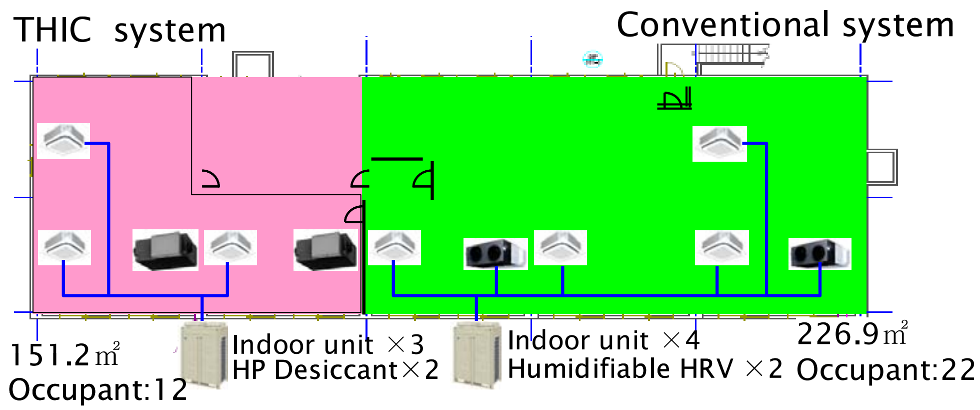


Figure 12 : Outline of Field Test Site

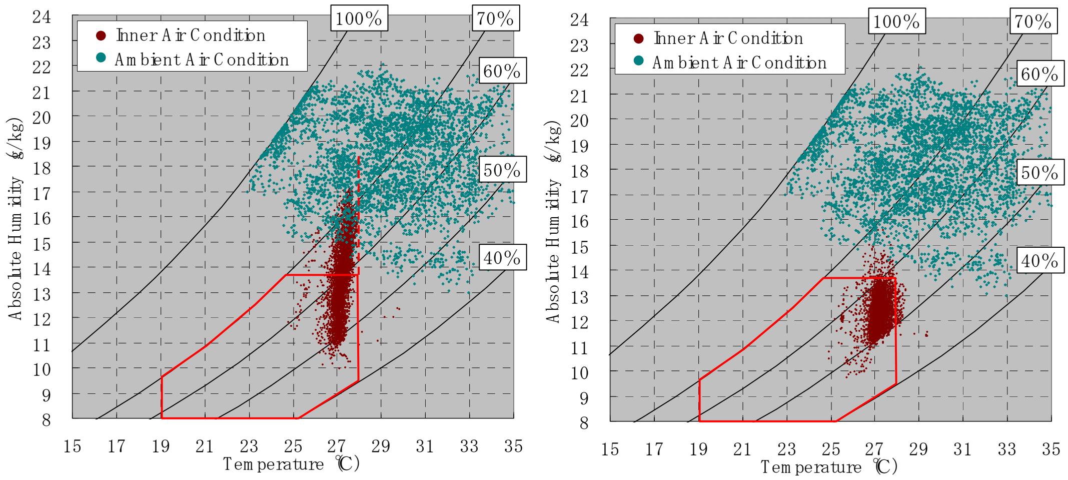
For the eastern area of the office, a combined system of conventional VRF and humidifiable HRV was installed as a conventional system. For the western area, a combined system of HP desiccant and sensible capacity enhanced VRF was installed as a THIC system. It was not possible to make the size of both areas even. So, the evaluation hereafter is according to the value divided by the area size.

4.1 Result of the Summer Test

The summer test was carried out from June to September. To evaluate the comfort level and energy saving, the temperature & humidity of the room and energy consumption were measured.

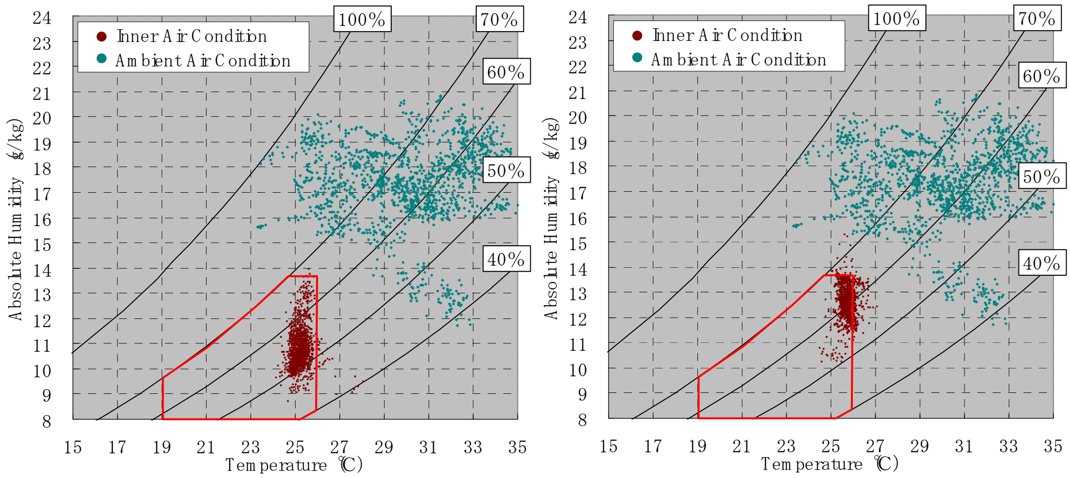
4.1.1 Inner Room Condition

Figure 13 and Figure 14 show the comparison of the inner room conditions of conventional and THIC systems, respectively.
When the set temperature is 28 deg C, the conventional system cannot provide adequate dehumidification capacity. And with the set temperature of 26 deg C, the conventional system over-dehumidifies the room air and consumes too much electricity. On the contrary, the THIC system can control the inner room condition around the edge of the target conditions on both set temperatures.



Conventional System THIC System

Figure 13 : Inner Air Condition (Set Temperature is 28℃)



Conventional System THIC System

Figure 14 : Inner Air Condition (Set Temperature is 26℃)

In Japan, it was common to set the target temperature to 26 deg C. But after the 3.11 disaster, it became common to set it to 28 deg C to correspond with the lack of electricity. However, this result shows that the conventional air conditioning system, without humidity control function, cannot maintain a comfortable air condition in a humid summer like in Japan, if the set temperature is 28 deg C.

The results of a questionnaire based survey to persons staying in the room also shows that the THIC system can provide a more comfortable condition than the conventional system as shown in Figure 15.

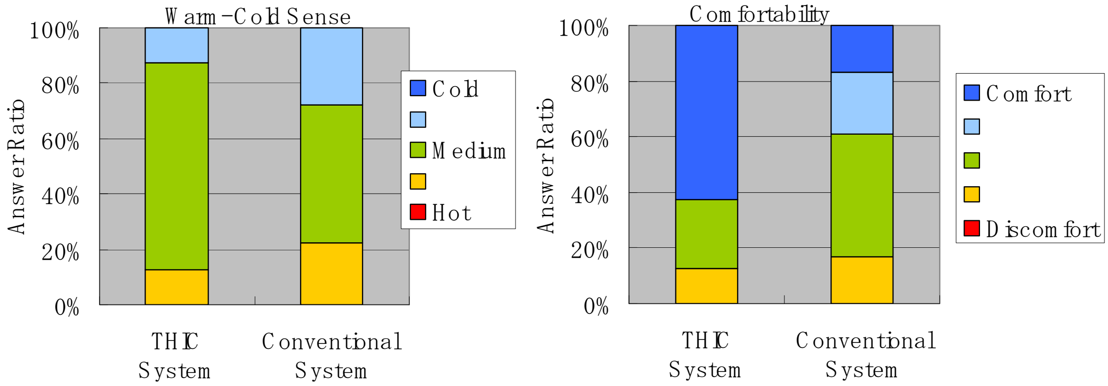
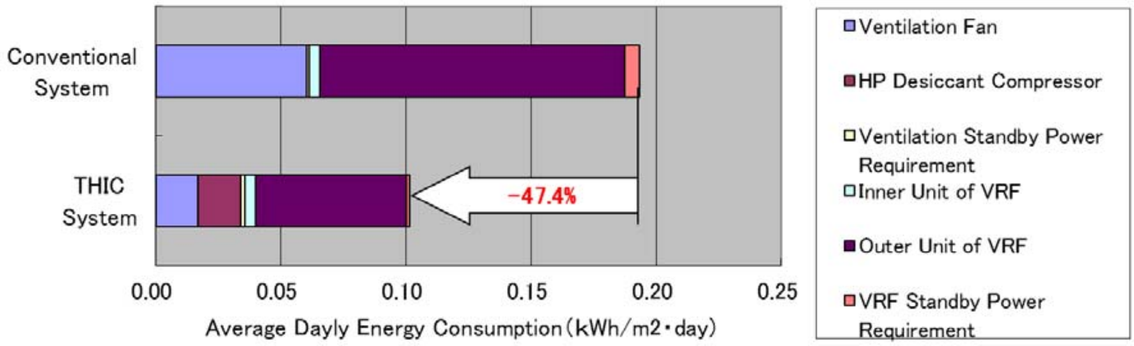


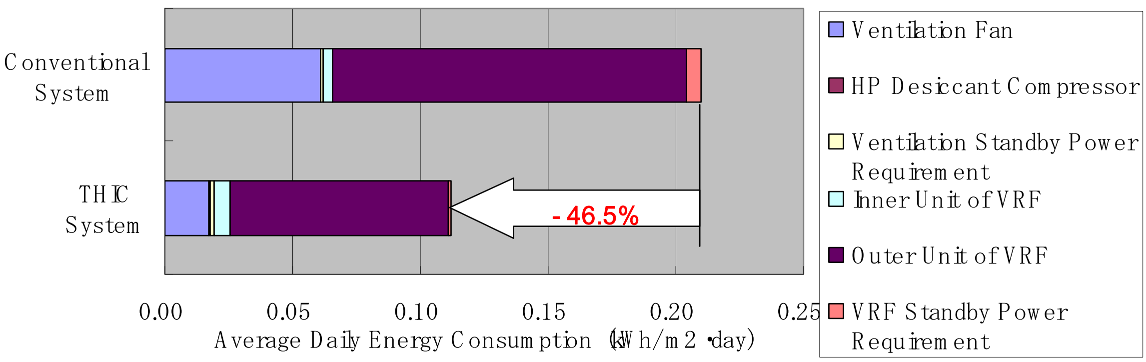
Figure 15 : Result of Questionnaire

4.1.2 Energy Consumption

Figure 16 shows the comparison of the integrated energy consumption of the test period.



Set Temperature is 28 deg C



Set Temperature is 26 deg C

Figure 16 : Daily Energy Consumption

The energy conservation effect of the THIC system in summer goes up to almost 50%.

4.2 Result of the Winter Test

The winter test is carried out from December to February, also by measuring the temperature and the humidity of the room and energy consumption.

4.2.1 Inner Room Condition

Figure 17 shows the comparison of the inner room conditions of the conventional and THIC systems, respectively.

Different from the results of the summer test, under the effect of humidifiable HRV, both the conventional and THIC system can control the inner air to the target condition.

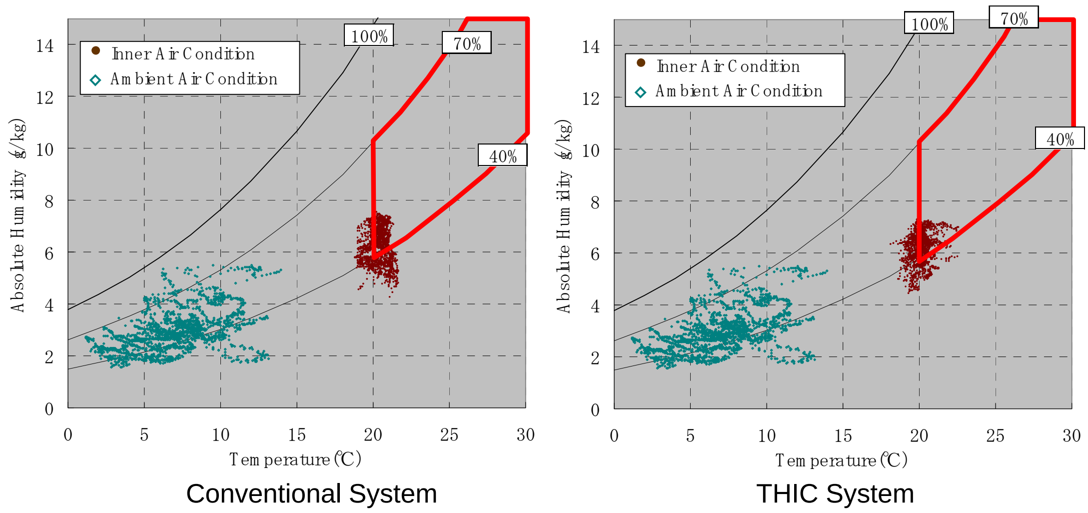


Figure 17 :InnerAirCondition (Set Temperature is 20℃)

4.2.2 Energy Consumption

Figure 18 shows the comparison of the integrated energy consumption of the test period.

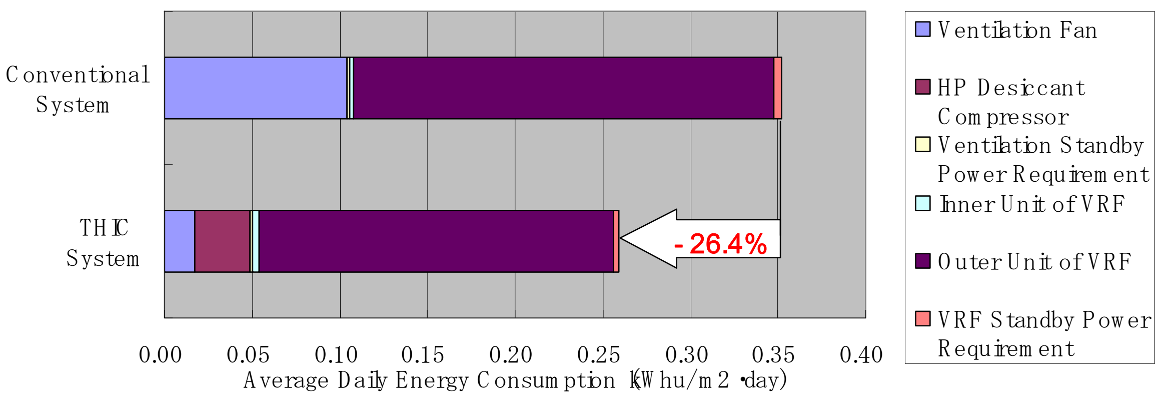


Figure 18 : Daily Energy Consumption

The energy conservation effect of the THIC system in summer goes up to almost 30%.

5 ANNUAL EVALUATION USING SIMULATION

As the sensible capacity enhanced VRF is characterized by its high efficiency in low load factor and low ambient temperature conditions like Spring and Fall, the difference between the conventional system and the THIC system is assumed to be greater in annual operation. The efficiency of the THIC system in an annual operation was evaluated by simulation. The simulation model was established using the data of the demonstration test. The evaluation was conducted on the assumption that the system is installed in a highly insulated building.

The energy simulation model is based on the Life Cycle Energy Management Simulation Tool (LCEM simulation), which is supplied by the National Land and Transportation Ministry of Japan. It can calculate the energy consumption based on the inputted air-conditioning load according to the result from building simulation.

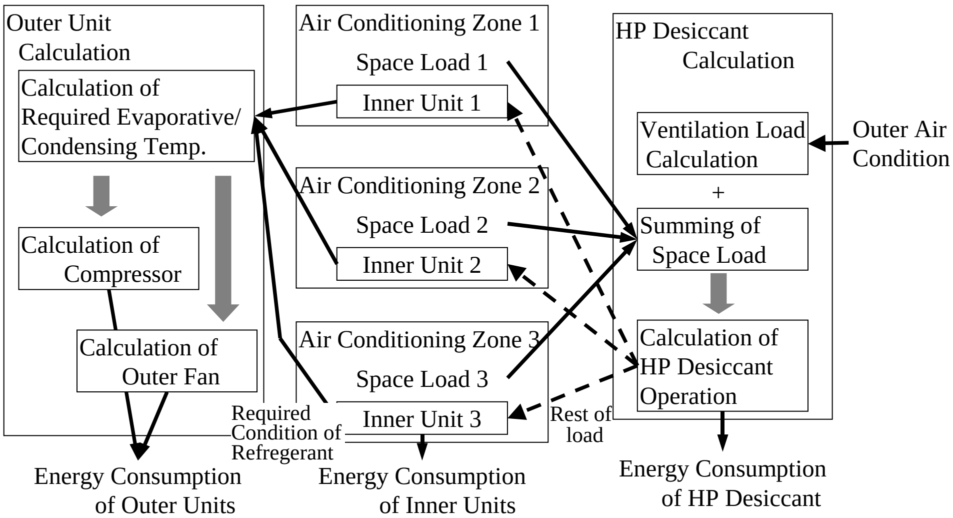


Figure 19 : Outline of THIC System Simulation Model

The accuracy of this simulation model is ensured by the comparison of the measured and calculated energy consumptions to fulfill the measured air-conditioning load of a demonstration test as shown in Figure 20.

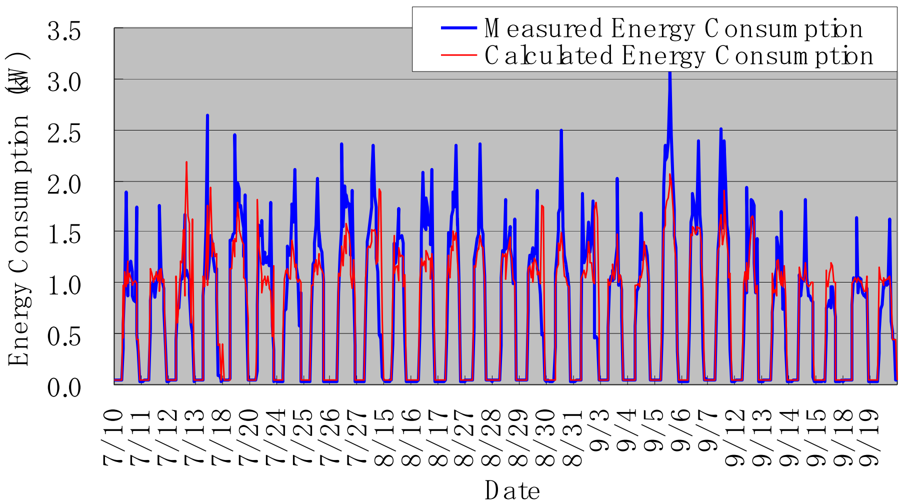


Figure 20 : Accuracy Test of the Simulation

The annual effect for energy conservation of the THIC system is calculated by this simulation. The calculation condition is shown in Table 1.

Table 1 : Condition of Simulation Comparison.

	Building	In Room Heat Generation	HVAC System	Set Indoor Air Condition	
				Cooling	Heating
Conventional System	Highly Insulated	10 W/m^2	Conventional VRF + Humidifiable HRV	26 degC 50%	22 degC 40%
THIC System			Sensible Capacity Enhanced VRF + HP Desiccant	28 degC 60%	20 degC 40%

As a result, about 74% of the energy consumption can be reduced.

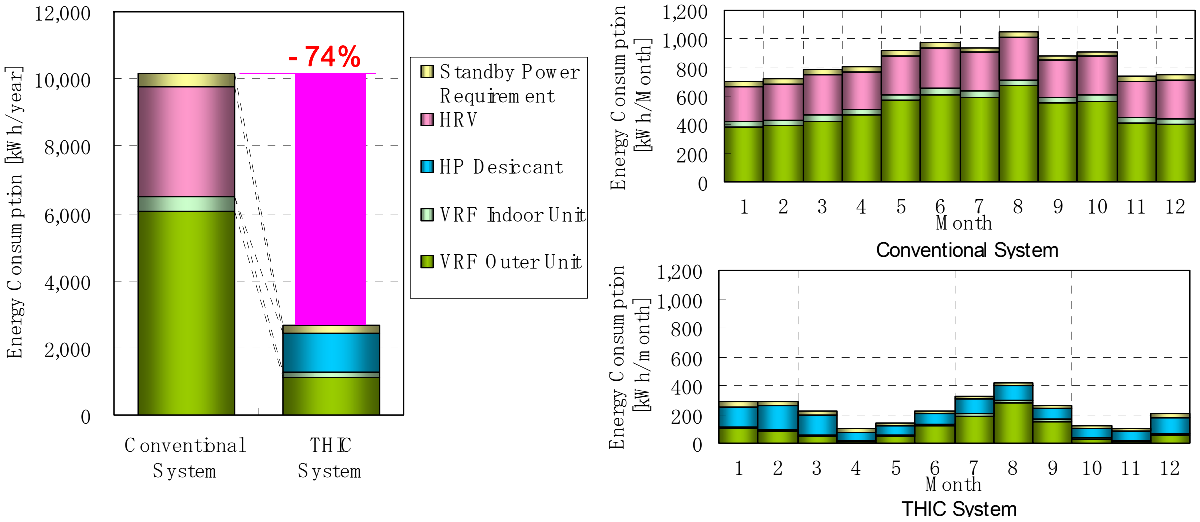


Figure 21 : Evaluation of the Total Energy Saving by Simulation

Figure 21 shows that the energy consumption of the Spring and Fall is drastically reduced.

6 CONCLUSION

The developed THIC system can maintain a comfortable inner air condition and drastically reduce the energy consumption at the same time.

This brilliant result is derived from the 3 points shown below:

- The reduction of the air-conditioning load through the individual control of temperature and humidity.
- The development of the HP desiccant for efficient humidity control.
- The development of the sensible capacity enhanced VRF for efficient temperature control; especially in spring or fall.

Through the installation of this THIC system, the ZEB will be realized with comparative ease in the case of two or three storey buildings. Moreover, it will also achieve a great amount of energy savings in high-rise buildings as well.

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