AIR-CONDITIONING SYSTEM WITH "HUMIDITY" AND "TEMPERATURE" INDIVIDUAL CONTROL THAT USES HIGHLY EFFECTIVE COMPACT DESICCANT SYSTEM

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Abstract: Desiccant system with adsorbent that does not require water supply nor cooling has been used for humidity control. But its efficiency was quite low because it requires high temperature (100 deg-C approx.) to desorb the adsorbent, and the system was quite large because it requires huge volume for adsorbent rotor. By directly coating the adsorbent on the surface of air-to-refrigerant heat exchanger for direct heating desorption and direct cooling adsorption, the heat pump desiccant system, which we call DESICA, enables the adsorbent to be regenerated at the condensing temperature of heat pump (40 deg-C approx.) and to be utilized its adsorption capacity to the limit. Because of this technology, DESICA achieved overwhelmingly high performance, about 2.5 times higher, and drastic volume reduction, about 1/3, compared to conventional desiccant dehumidifiers.

Key Words: heat pumps, desiccant, efficiency

1 INTRODUCTION

A great amount of world energy demand is associated with the building environment. It is estimated that air conditioning (AC) and Heat pumping systems consume about 50% of the total electricity use in the office buildings (Huang et al., 2006; Zhou et al., 2007). So the reductions of energy consumption in AC systems are strongly required.

Under this situation, one solution to improve the performance of heat pump AC systems is to reduce the pressure difference between condensing pressure and evaporating pressure while improving the performance of elements such as compressors and heat exchangers. But this solution leads to higher evaporating temperature resulting to less dehumidification capacity. Fig.1 shows the relationship between energy efficiency and latent heat factor. It is obvious from the figure that higher evaporating temperature raises the energy efficiency but greatly reduce the latent heat factor at the same time.

This means that the current AC system, which dehumidifies the indoor air with evaporating temperature lower than the dew point of the inlet air to the indoor unit, cannot sufficiently dehumidify and the residents may feel humid when it is controlled with the dry bulb temperature. When it is controlled with the wet bulb temperature, or the humidity, the dry bulb temperature goes lower resulting to excessive energy consumption. There is such a trade-off between dehumidification and energy efficiency that the improvement of AC system performance was limited when the comfort of residents are considered.

To solve this problem, a system that controls “Humidity” and “Temperature” individually was developed. Different from conventional AC systems that deal with temperature and humidity with one mechanism, the developed system can control both temperature and humidity by individual mechanisms to each set values. It achieves higher energy efficiency and comfort of residents at the same time.

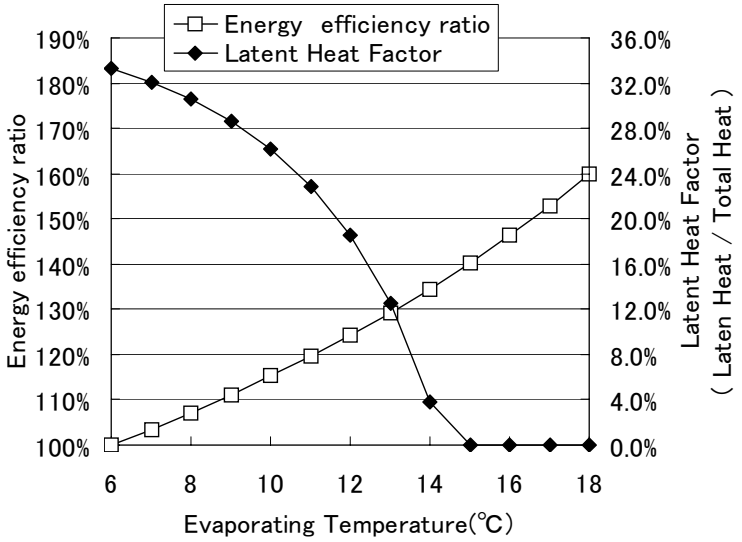


Figure1 :Energy efficiency ratio and dehumidification

2 HIGHLY EFFECTIVE COMPACT DESICCANT SYSTEM “DESICA”

For the humidity and temperature individual control system, it is very easy to build the temperature control mechanism with higher evaporating temperature. So the development was mainly dedicated to the high efficient humidity control mechanism.

2.1 Problems in Conventional Dehumidifiers

In conventional mechanism, dehumidification has been achieved by low evaporating temperature cooling. But, as described in Fig. 1, it has been very difficult to obtain high efficiency with such mechanism. So we paid attention to the desiccant mechanism that dehumidifies by adsorption of humidity.

Fig. 2 shows the image of conventional desiccant dehumidifiers with rotors.
With this mechanism, the humid ambient air goes through the adsorbent embedded adsorption rotor and dehumidified and cooled by the sensible heat recovery rotor before supplied to indoor. The indoor air slightly heated by the sensible heat recovery rotor is heated by a heat source and desorbs the wet rotor. Fig.2 shows the process in the psychrometric chart.

It is obvious from Fig.2 that there is a theoretical limitation in the adsorption of humidity. To dehumidify the ambient air with 33 deg-C and 22.0g/kg to 9.0g/kg, theoretical desorption temperature of 64 deg-C is required. In reality, heat transfer losses between heat exchanger, rotor and air makes the required desorption temperature higher (80 to 100 deg-C approx.). This is because such systems have been introduced only in special cases where high temperature exhaust heat such from gas engine is available or especially dry air, which cannot be achieved by separated adsorption, and cooling is required.

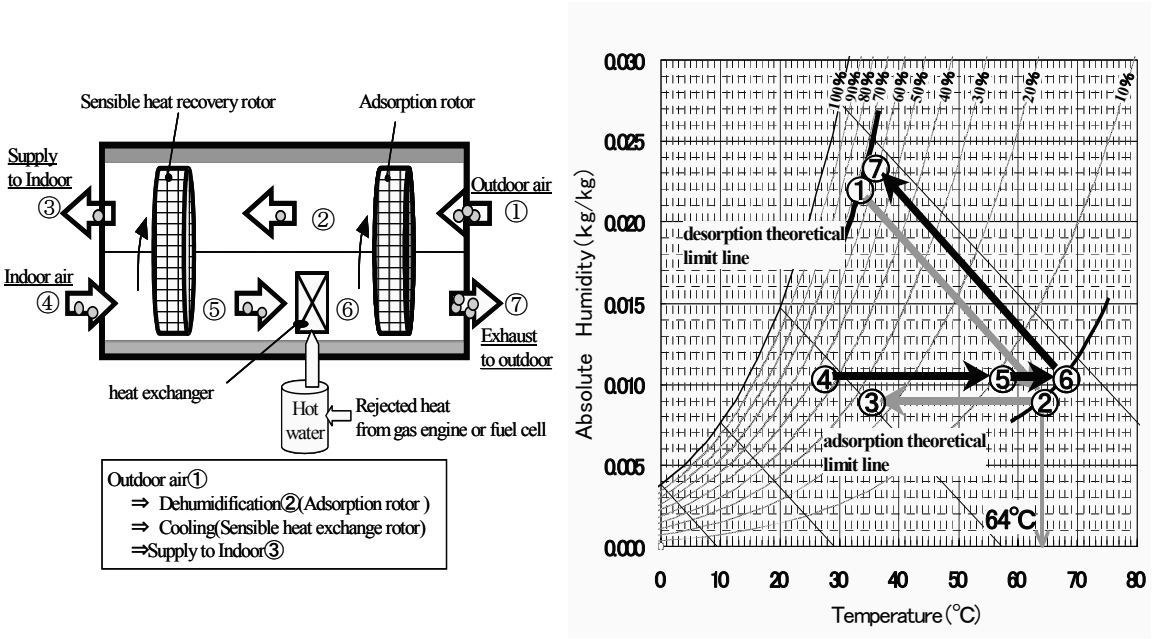


Figure2: Psychrometric chart (2rotor type)

2.2 Direct Cooling Adsorption and Direct Heating Desorption

Great improvements for both capacity and performance were required for the desiccant dehumidifiers to popularize as general AC system. To improve the performance, low temperature desorption of adsorbent with condensing temperature of heat pump unit (40 deg-C approx.) was evaluated by theoretical calculation. Fig.3 shows the calculated results of direct cooling adsorption and direct heating desorption.

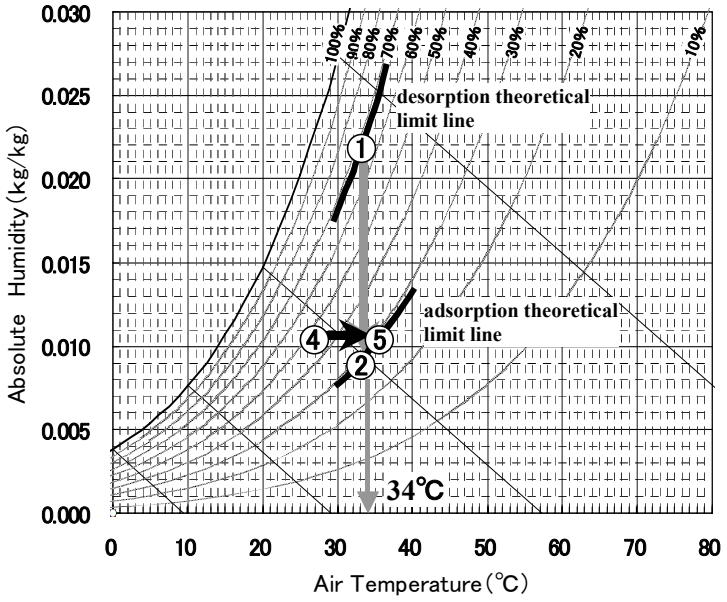


Figure3: Psychrometric chart (direct cooling adsorption direct heating desorption)

The evaluation shows it is possible to reduce temperature of desorption to 34deg-C with the same air condition in Fig.3 which is available by ordinary heat pump condensing temperature.

2.3 Hybrid DESICA Element

To materialize the direct cooling adsorption and direct heating desorption, the heat exchanger for AC system coated with adsorbent was developed. It is called the Hybrid DESICA Element. Fig. 4 shows the outlook and structure of Hybrid DESICA Element.

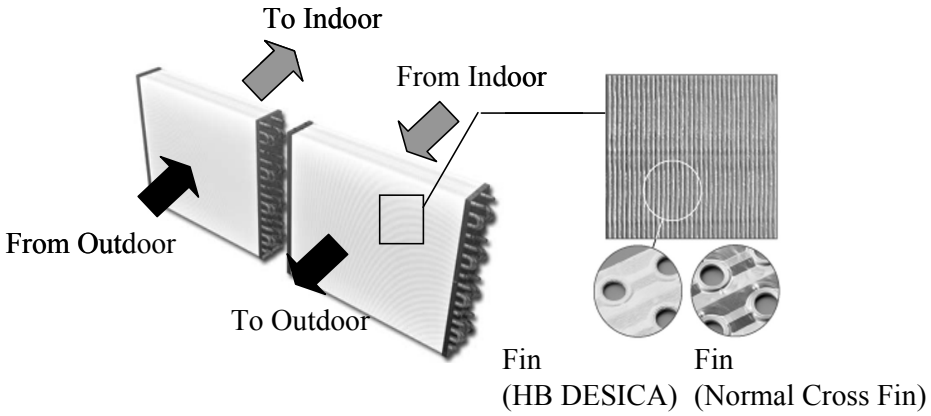


Figure 4: Hybrid DESICA Element

The element consists of ordinary fin-and-tube heat exchanger whose fin surface is coated by adsorbent film. Challenges such as preventing the exfoliation by the difference in linear thermal expansion coefficient of aluminum and adsorbent film, thick and uniform film formation to adsorb sufficient humidity within narrow fin pitch, and establishment of mass production method and so on have been overcome. Now the system is in mass production.

2.4 Operation Principle of DESICA

The development of heat pump cycle utilizing the Hybrid DESICA Element (HDE) followed. DESICA mechanism consists of compressor, two HDEs, electric expansion valve, 4-way valve, supply air fan, exhaust air fan, eight dumpers to switch air flows and two dampers for bypass. The operation principle of DESICA is shown in Fig. 5

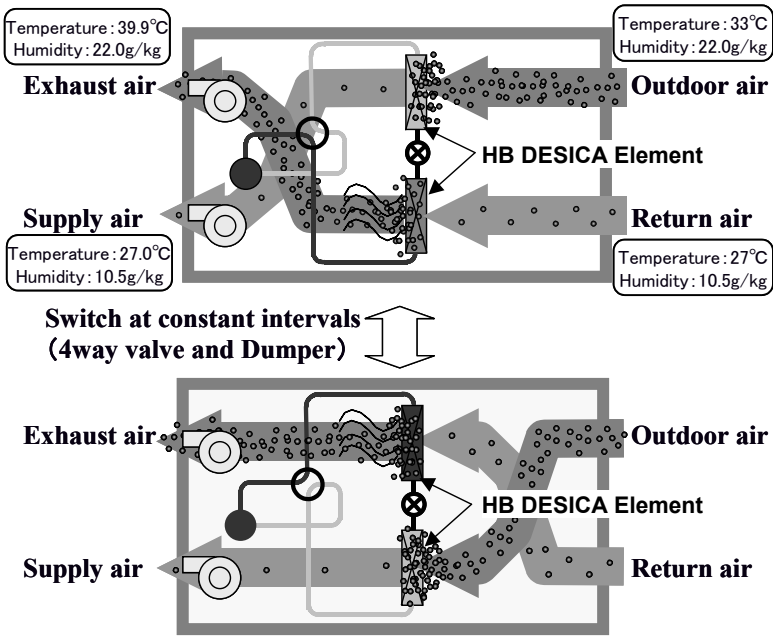


Figure 5: Operation Principle(DESICA)

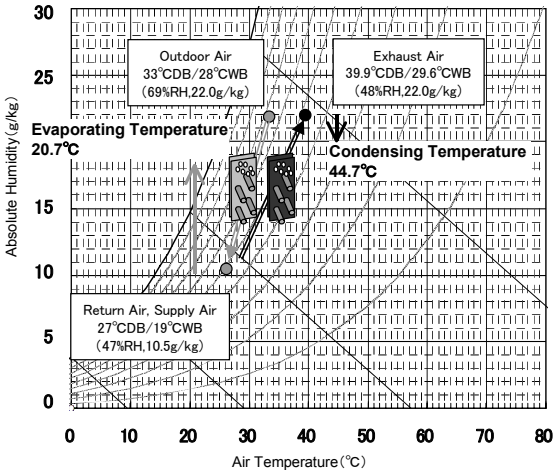


Figure 6: Psychrometric Chart(DESICA)

The outdoor air is introduced to the adsorption side of the HDE that is cooled by the evaporation of refrigerant, dehumidified, cooled and supplied to indoor. The indoor air is introduced to the desorption side of the HDE which is heated by the condensation of refrigerant, humidified with released humidity and exhausted to outdoor at the same time. After the HDEs are fully adsorbed or desorbed, the airflows and refrigerant flow are switched periodically to achieve continuous dehumidification. The airflows are switched by the dampers, and the refrigerant flow is switched by the 4-way valve.

Fig. 6 shows the operation process in psychrometric chart. Because of the direct cooling adsorption and direct heating desorption, the operation is not limited by the adsorption theoretical limit. This is why DESICA enables high dehumidification capacity with lower desorption (condensing) temperature and higher adsorption (evaporating) temperature.

2.5 Capacity of DESICA

Table 1 shows the specifications of DESICA.

Table1: Specification (DESICA)

Dehumidifying Performance	Indoor 27 deg-CDB,19 deg-CWB Outdoor 33 deg-CDB,28 deg-CWB	Total Heat	kW	5.5
		Sensible Heat	kW	0.9
		Power Consumption	W	1300
	Indoor 27 deg-CDB,19 deg-CWB Outdoor 33 deg-CDB,28 deg-CWB	Total Heat	kW	2.4
		Sensible Heat	kW	0.9
		Power Consumption	W	400
Humidifying Performance	Indoor 22 deg-CDB,50%RH Outdoor 0 deg-CDB,50%RH	Total Heat	kW	7.1
		Sensible Heat	kW	4.4
		Power Consumption	W	1700
		Humidification	kg/h	3.78
	Indoor 20 deg-CDB,13.8 deg-CWB Outdoor 7 deg-CDB,6 deg-CWB	Total Heat	kW	2.7
		Sensible Heat	kW	1.9
		Power Consumption	W	400
Dimensions	Height×Width×Depth		mm	450×1300×1000
Weight			kg	155

High adsorption and desorption capacity by the direct cooling adsorption and direct heating desorption was combined with highly efficient vapor compression heat pump. This hybrid mechanism achieved powerful dehumidification capacity and approximately 2.5 times higher performance compared to the conventional desiccant dehumidifiers.

Also because the number of elements was reduced by utilizing the Hybrid DESICA Element and the heat loss was reduced to improve heat exchanger efficiency by the direct cooling and heating, DESICA is made to be very compact, whose volume is to be the 1/3 of the conventional desiccant dehumidifiers with the same capacity.

3. FIELD TEST

High efficient humidity control ventilating system “DESICA” and high efficient VRV with higher evaporating temperature were combined for humidity and temperature individual control and tested in the field. The test was held in an urban area (Osaka).

3.1 Installation Condition and Test System

Installation condition and test system are shown in Fig. 7. The system was installed in the 2nd floor of seven-floor building. The 216m^2 floor was used for office with about 25 residents. The floor was originally equipped with three 350m^3/h heat recovery ventilation units and 40kW VRV. This system was used as reference to the test system. Two DESICA units with 500m^3/h ventilation capacity were installed to have the same ventilation capacity with the reference system. VRV system was reorganized to enable higher evaporating temperature when operated with DESICA units. The operation of test system and reference system were managed by scheduler to switch daily in turn.

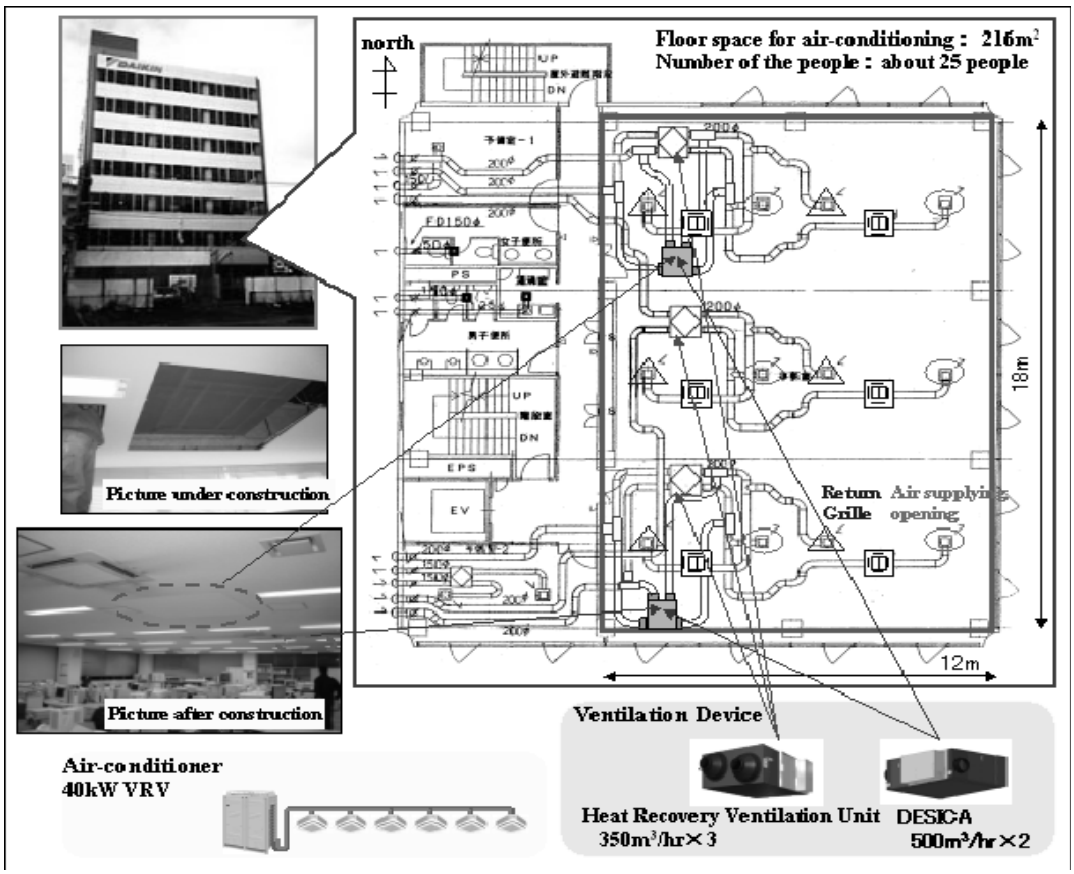
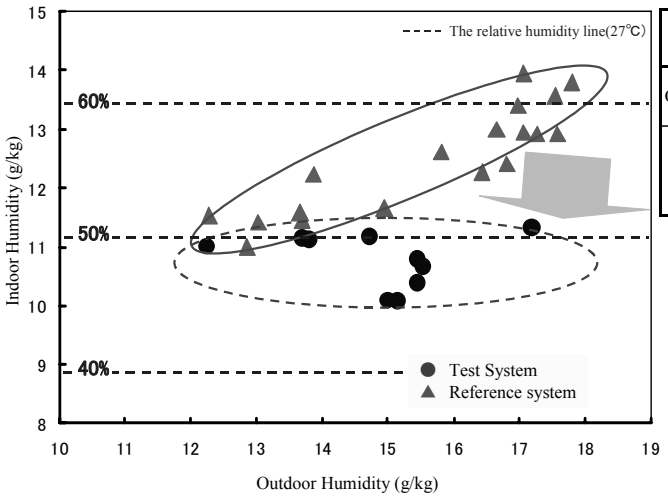


Figure 7: Floor layout

3.2 Field Test Result (Summer)

The operation results of test system and reference system in summer season were plotted by daily average humidity (8:30am to 5:00pm) as indoor against outdoor in Fig. 8. The relative humidity at indoor temperature of 27deg-C is designated with dashed lines in Fig. 8. The seasonal averages are compared in Table (Fig. 8.)



			Test system (10days)	reference system (18days)
Outdoor	Temperature	℃	32.4	31.2
	Humidity	g/kg	14.8	15.6
Indoor	Temperature	℃	26.2	25.5
	Humidity	g/kg	10.8	12.5
		RH%	51	61

−4.0g/kg −3.1g/kg

Figure 8: Comparison of indoor and outdoor average humidity (Summer)

Comparing the seasonal average, the test system dehumidifies about 30% more compared to the reference system without lowering the indoor temperature. Also, the relative humidity shows the test system dehumidifies to 50%RH regardless of the outdoor condition. These results show that more comfort indoor condition can be achieved with the test system.

Energy consumptions were evaluated by the system energy efficiencies. The seasonal average of daily system energy efficiencies (8:30am to 5:00pm) for test system and reference system are compared in Fig. 9. The system energy efficiency is defined as the total capacity of all equipment in the system divided by the total power consumption of all equipment in the system. The test system shows higher efficiency by the individual control of humidity by "DESICA" and temperature by "Sensible Capacity Enhanced VRV." The seasonal average system energy efficiency shows 3.8 for reference system and 4.8 for test system, which is an improvement of 26%.

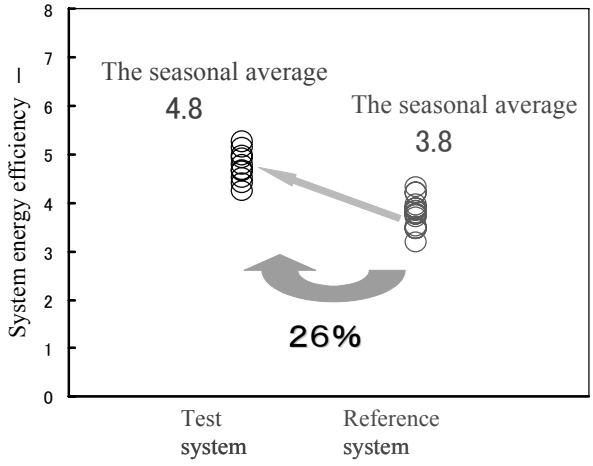
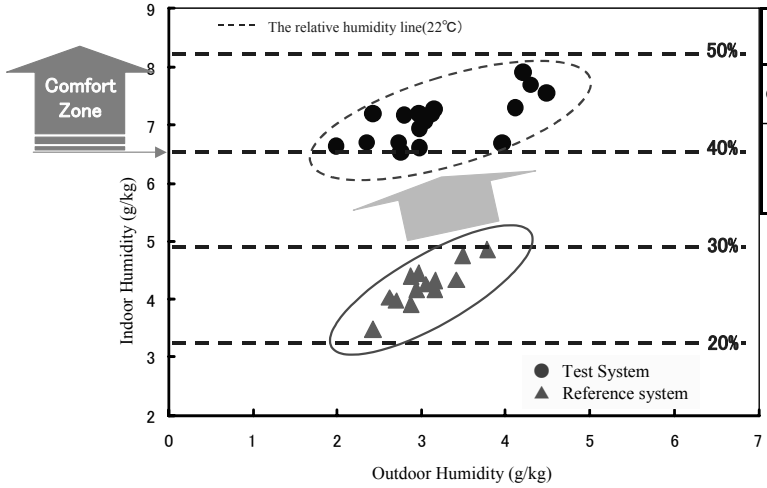


Figure 9: Comparison of seasonal average system energy efficiency (Summer)

3.3 Field Test Result (Winter)

The operation results of test system and reference system in winter season were plotted by daily average humidity (8:30am to 5:00pm) as indoor against outdoor in Fig. 10. The relative humidity at indoor temperature of 22deg-C is designated with dashed lines in Fig. 10. The seasonal averages are compared in Table (Fig. 10)



		Test system (28days)	reference system (15days)
Outdoor	Temperature	10.4	11.4
	Humidity	3.3	3.4
Indoor	Temperature	23.1 +3.6g/kg	23.5 +1.1g/kg
	Humidity	6.9	4.5
		40	25

Figure 10: Daily comparison of indoor and outdoor average humidity (Winter)

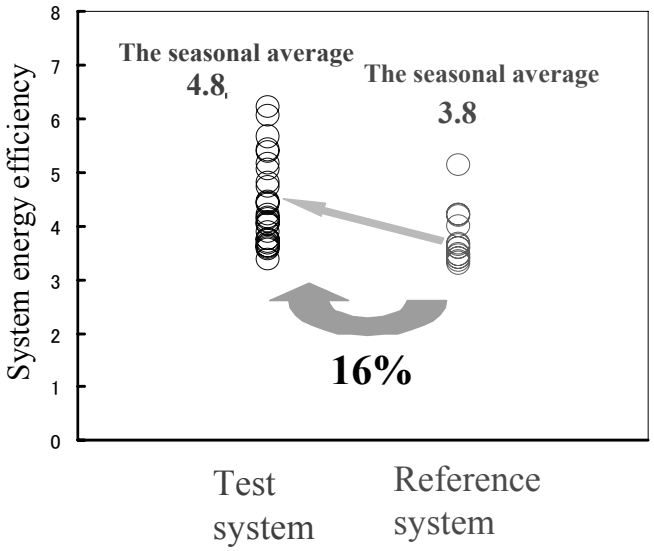


Figure 11: The daily average system energy efficiencies (Winter)

The seasonal average shows that more than 3 times higher humidification was achieved by the test system compared to the reference system. Also, the relative humidity shows that the test system keeps indoor humidity above 40%RH. This means a sufficient humidification was achieved.

Energy consumptions were evaluated by the system energy efficiencies. The seasonal average of daily system energy efficiencies (8:30am to 5:00pm) for test system and reference system are compared in Fig. 11. The seasonal average system energy efficiency shows 3.8 for reference system and 4.4 for test system, which is an improvement of 16%.

4 CONCLUSIONS

High efficient humidity control ventilating system “DESICA” and “Sensible Capacity Enhanced VRV” with higher evaporating temperature were combined to achieve “Humidity” and “Temperature” individual control system. By utilizing the Hybrid DESICA Element consists of a heat exchanger whose fins are coated with adsorbent, DESICA enables:

- Low temperatures desorption, that exhaust heat from heat pump (condensing heat) can be utilized.
- Approximately 2.5 times higher efficiency by the hybrid with heat pump cycle compared to conventional desiccant dehumidifiers.
- Approximately 1/3 compactness by direct cooling and heating of adsorbent to reduce heat loss compared to conventional desiccant dehumidifiers.

Also the “Humidity” and “Temperature” individual control system was tested in filed. The results show:

- Capability of keeping indoor humidity below 50%RH
- 26% seasonal average system energy efficiency improvement in summer compared to the combination of heat recovery ventilation and fixed evaporating temperature VRV
- Capability of keeping indoor humidity above 40%RH in winter.
- 16% seasonal average system energy efficiency improvement in winter compared to the combination of heat recovery ventilation and fixed evaporating temperature VRV.

The system proved to have the capability of reduction of energy consumption while maintaining indoor comfort throughout the year.

5 REFERENCES

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