Performance Simulation of a Novel Solid Desiccant Heat Pump System in Energyplus

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ABSTRACT

The variable refrigerant volume (VRV) air conditioning system usually needs to be operated with a ventilation system, since the VRV system cannot provide fresh air. The commonly used ventilation unit with the VRV system is the heat recovery ventilation (HRV) unit. In this study, a novel solid desiccant heat pump unit (DESICA) is proposed and performance of this unit is investigated by simulation, while a new type of high sensible heat VRV (HSHVRV) is developed. Mathematical model of DESICA is developed based on the generic dynamic building energy simulation software – EnergyPlus, while the model of HSHVRV is developed based on the standard VRV model. Energy consumption of joint DESICA and HSHVRV system (JDHVS) is compared with the energy consumption of joint HRV and standard VRV system (JHSVS) in an office building, while system performance is investigated in the meanwhile. It is found that the JDHVS can keep indoor humidity ratio at about 50% RH, resulting in a better indoor thermal comfort than JHSVS. Also, simulation results show that the energy-saving potential of the JDHVS system can achieve 20% in cooling conditions and 20% in heating conditions, compared with the JHSVS, respectively.

KEYWORDS

Performance simulation, Solid desiccant heat pump, VRV, Energy saving, EnergyPlus

INTRODUCTION

A great amount of world energy demand is connected to the building environment, and it is estimated that heating ventilating and air conditioning (HVAC) systems consume about 50% of the total energy consumption in the office buildings. As known, the conventional air conditioner wastes much energy while handling the sensible and latent load together and cannot ensure a good thermal comfort. Lately, independent control of temperature and humidity system (ICTHS) has come into being. The desiccant cooling subsystem will be in charge of the latent load, while traditional VCS will deal with sensible load. As a result, energy saving can be achieved while ensuring a better thermal comfort. According to this, DAIKIN developed a novel ICTHS, in which a novel solid desiccant heat pump (DESICA)

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will deal with the latent load and a new type of high sensible heat VRV is in charge of the sensible load. Usually, the VRV systems usually need to be installed with some additional ventilation device, since the VRV system cannot supply any fresh air itself. The most commonly used ventilation device used with VRV is the heat recovery ventilation systems. However, they cannot provide effective dehumidification during the heat recovery (Aynur, Hwang et al. 2008). In Aynur`s (2010) study, the experimental data related to the integration of the VRV and DESICA systems was provided. The integration was found to be promising in terms of energy saving of the VRV systems and better indoor thermal comfort.

So far, there is no well-known energy simulation software available yet which can be used for the energy analysis of the new DESICA system. Based on the generic dynamic building energy simulation software, this paper investigates energy features of the DESICA system and develops a new model, to evaluate the performance and energy consumption of the DESICA system. Using the model developed in EnergyPlus, energy consumption of JDHVS is compared with that of JHSVS in an office building in Shanghai, while system performance is investigated in the meanwhile.

SYSTEM DESCREPTION

The schematic diagram of DESICA is shown in Fig. 1. With four inlets and outlets in total, namely supply air (SA), outdoor air (OA), return air (RA), exhaust air (EA), and two fans located at the SA and EA outlets, DESICA consists of the main parts compared to the conventional heat pump, namely, two heat exchangers, expansion valve, compressor and a 4-way valve as well. The only difference is that the traditional heat exchangers are replaced by the novel desiccant humidification/dehumidification heat exchanger, which is made by directly coating solid desiccant materials onto the surface of the fin tubes of the heat exchangers.

In the cooling condition, during the first cycle, as shown in Fig. 1, in the air loop, OA flows into the system through the lower heat exchanger, which acts as evaporator. In the refrigerant loop, meanwhile, the throttled refrigerant enters the evaporator at a very low temperature and cools down the desiccant material coated on the surface of the fin tube, which helps the evaporator cool down the OA, and dehumidify the OA, while desiccant material adsorbs the moisture because of its low surface partial pressure of water. As a result, hot humid OA is processed into cool dry SA and supplied into the indoors.

Meanwhile, on the other side, RA flows through the upper heat exchanger, which acts as condenser. In the refrigerant loop, the discharged refrigerant from the compressor enters the condenser at a very high temperature and heats the desiccant material coated on the surface of the fin tube, which helps the desiccant material desorbs the moisture because of its high surface partial pressure of water. As a result, the desiccant material completes regenerating and the hot humid EA is exhausted to the ambient.

A 4-way valve helps convert into the second cycle by replacing the two heat exchangers by each other. Two air dampers help adjust the flow direction so that OA always flows through the evaporator with the help of the supply fan and RA flows through the condenser with the help of the exhaust fan. As a result, the whole system keeps nonstop working.

In the heating condition, the system works almost same as the cooling condition, except for the function of the two desiccant humidification/dehumidification heat exchanger. In this condition, OA flows through condenser to get heating and humidifying while RA flows through evaporator to get cooling and dehumidifying.

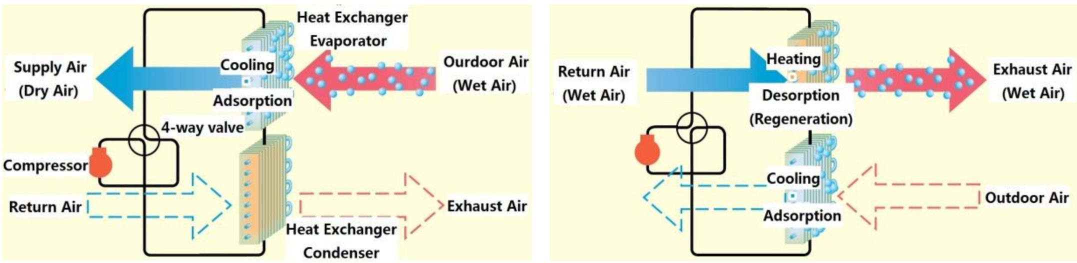

Figure 1. *Schematic diagram of DESICA*

MODELING AND PROGRAMMING

System calculation in this study is based on the building simulation program, EnergyPlus, which employs the heat balance engine with HVAC system integrated into the building simulation. Since DESICA system is a novel stand alone working unit, the model of DESICA system is established as a new module in the ZoneEquipments. The model of DESICA is established in the EnergyPlus source codes following the flowchart as shown in Fig. 2

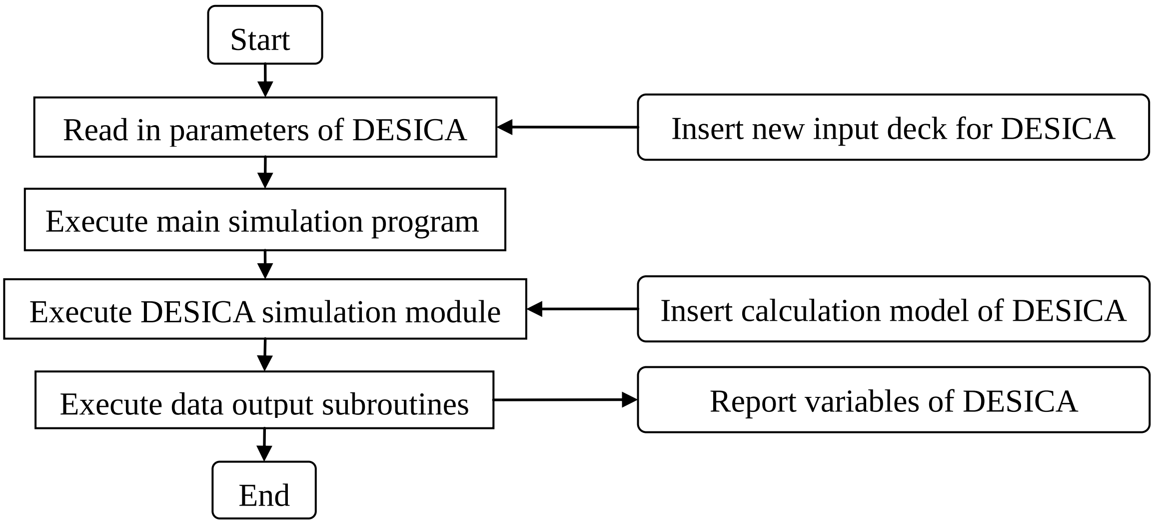

Figure 2. *Schematic flowchart of the compiling process of DESICA system*

According to the technical material supplied by DAIKIN, the performance and energy consumption of DESICA can be calculated according to the outdoor and indoor conditions. The uniform function is shown as equation (1).

$$D = f(T_{OA}, T_{RA}, X_{OA}, X_{RA}, PLR) \quad (1)$$

where $T_{OA}, T_{RA}, X_{OA}, X_{RA}$ represent for outdoor and indoor temperature (^{o}C) and humidity ratio (kg/kg), PLR is the part load ratio, and D represent for the performance and energy variables For the novel JDHVS, iteration is inserted in DESICA module, so that DESICA and

HSHVRV can cooperate to match the air conditioning load. Fig. 3 shows the flowchart of the calculation process of JDHVS.

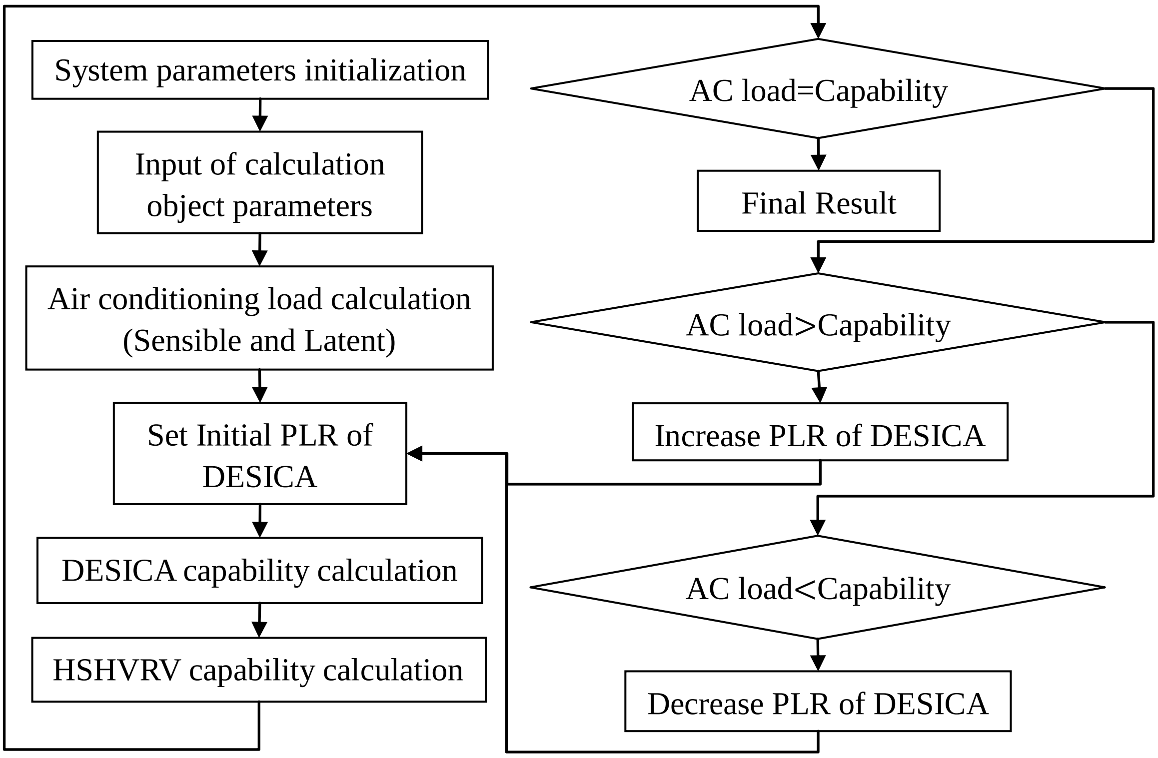

Figure 3. *Schematic flowchart of the calculation program for JDHVS*

SIMULAITON AND DISCUSSION

A single room is used to testify the simulation effect of the DESICA module embedded in EnergyPlus. The room is located at the newly built Green Energy Laboratory (GEL) in Shanghai Jiao Tong University. The room is used as student office with a constant occupancy. In this 72m^2 room, two types of ICTHS are installed, namely, JDHVS and JHSVS. Table 1 shows the summary of the key parameters of the simulation room. Fig. 4 shows the air conditioning loads calculated using the typical summer and winter design day in EnergyPlus. According to the loads, the HVAC systems are configured as shown in Table 1. To be mentioned that, the combination ratio of HSHVRV is 1.6, which means the total capability of indoor unit is 1.6 times of outdoor unit, while that of VRV is 1.0.

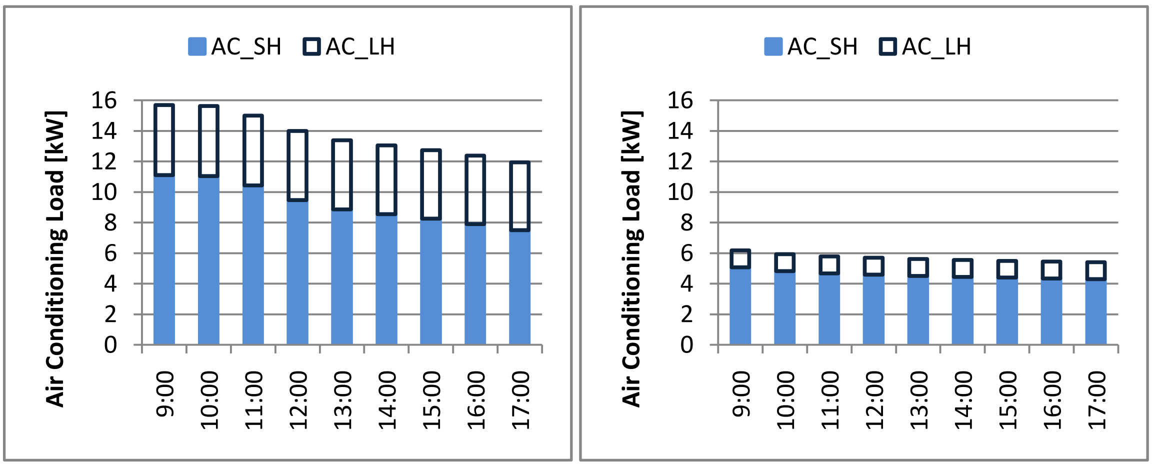

Figure 4. *Air conditioning load on typical design day: summer and winter*

Table 1. *Summary of the key parameters of the simulation room*

Items	Description
General information	
Location	Shanghai, China
Building type and stories	2^{nd} floor of the 3 stories Laboratory building
Area and height	11.2m×6.4m; 3.0m
Windows and shading	Double pane glazing, window height = 2.7m no shading device
Operation hours	Office time: 09:00-17:00
Design values of internal heat gains, ventilation, and infiltration	
Occupancy density	4.8 m^2/ person
Lighting density	5.6 W/ m^2
Plug equipments load	1800 W
Space design temperature and relative humidity	22^oC, 50% RH for winter design day $27\,^oC$, 47% RH for summer design day
Infiltration	0.28, air change per hour for each zone
Ventilation	30 m^3/(person*h)
HVAC systems	
DESICA sytem	HDMP50C ventilation volume: 450m^3/h
HRV system	VAM500GBS ventilation volume: 450m^3/h
VRVsystem	Outdoor unit： RXYP160B ×1 Indoor unit： FXYFP-MC36 ×2 +FXYFP-MC45 ×2
High SH VRV system	Outdoor unit： RXKP140A ×1 Indoor unit： FXYFP-MC45 ×5

Typical design day

Initial operations of the JDHVS and JHSVS are performed on typical summer and winter design day based on the weather file in EnergyPlus.

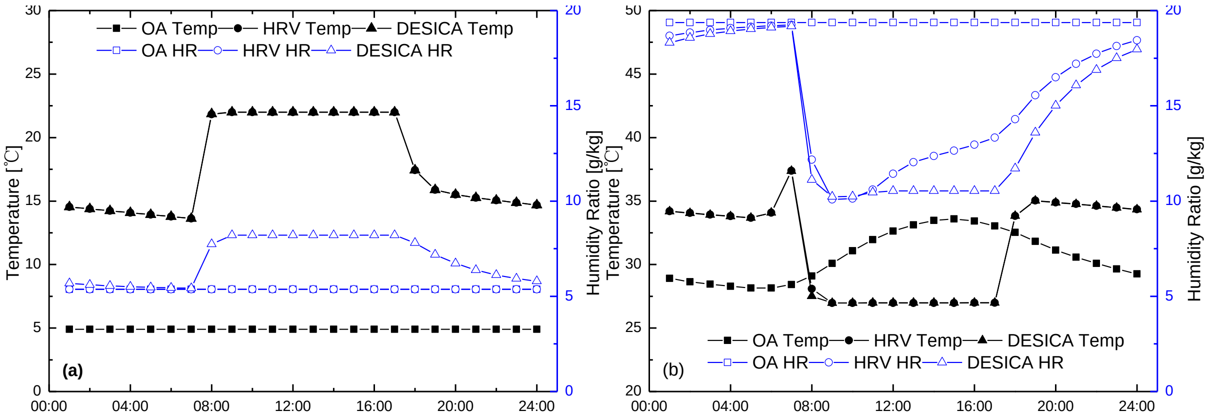

Figure 5. *Hourly indoor and outdoor condition: (a) winter; (b) summer*

Fig. 5 shows the indoor and outdoor conditions in the typical design days. Fig. 5a shows the condition in winter design day, while the outdoor temperature is set a constant value of 4.9^oC, and 5.36g/kg of humidity ratio according to the design day file in EnergyPlus. The two systems are set to start from 8:00 to warm up the room initially. As shown, temperature rises to the target of 22 ^{o}C for both systems, while the humidity ratio appears different. The DESICA system can well control the humidity to the target of 8.2g/kg (50% RH), but the HRV system results in 5g/kg of humidity. The same situation appears in summer design day shown in Fig 5b. In summer design day, the outdoor temperature ranges from 28.1 ^{o}C to 34.5 ^{o}C, while humidity is set 19.4g/kg constantly. From 8:00, temperature of both systems decreases to the target of 27 ^{o}C, while the humidity is better controlled of DESICA system to be 10.5g/kg than HRV system. The results show the advantage of DESICA dealing with the latent load, because DESICA will adjust its capability according to the air conditioning loads.

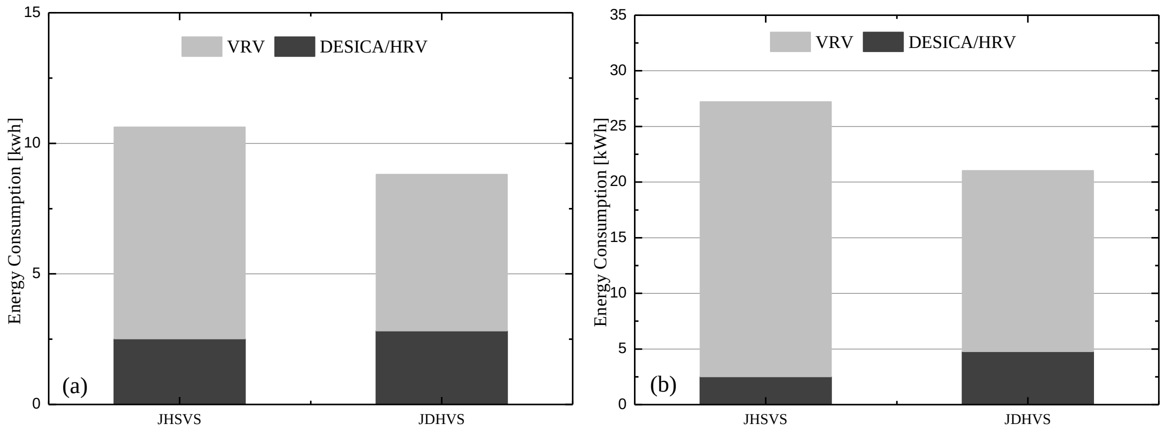

Figure 6. *Daily energy consumption in typical design day: (a) winter; (b) summer*

Fig. 6 shows the daily energy consumption in typical design day of the two systems. Fig. 6a shows the energy consumption in winter design day, while HRV system consumes 10.62kWh and DESICA system consumes 17% less of 8.81kWh. In Fig. 6b, HRV system consumes 27.2kWh while DESICA system consumes 22.8% less of 21kWh. The results show the energy saving of JDHVS, this is because DESICA deals with most latent loads and part of sensible load, leaving the HSHVRV less load comparing to the standard VRV in JHSVS. Moreover, the HSHVRV has a higher rated COP than the standard VRV.

Seasonal condition

With the same key parameters shown in Table 1, a series of simulations are performed in winter season and summer season to study an overall comparison of JDHVS and JHSVS. In Shanghai, the winter season starts form December to February of next year, while the summer season from June to August. For the seasonal simulation, we calculate the average outdoor air condition initially according to the weather file in EnergyPlus as shown in Table 2. Then the design day file of each month can be established in EnergyPlus by setting a constant dry bulb temperature and wet bulb temperature with the conditions in Table 2.

Fig. 7 shows the indoor conditions for two systems, respectively with 1 hour averaged data. It is found from Fig. 7a that all indoor air condition data provided by DESICA system falls in the target zone, while none provided by HRV system falls in the target zone because VRV and HRV cannot supply any latent capability in winter. In Fig. 7b, for the summer condition, all indoor condition data provided by DESICA system falls in the target zone, while 7% data provided by HRV system falls in the target zone. The results show the advantage of DESICA dealing with the latent loads.

Table 2. *Details of average outdoor air design conditions*

	Outdoor conditions		
	Dry Bulb T	Wet Bulb T	Humidity Ratio
June	24.3 ^{o}C	22.2^{o}C	16.0g/kg
July	27.5 ^{o}C	24.2 ^{o}C	19.1g/kg
August	27.0 ^{o}C	24.8 ^{o}C	18.9g/kg
December	7.43 ^{o}C	5.08 ^{o}C	4.48g/kg
January	4.51 ^{o}C	2.90 ^{o}C	4.00g/kg
February	6.31 ^{o}C	4.29 ^{o}C	6.31g/kg

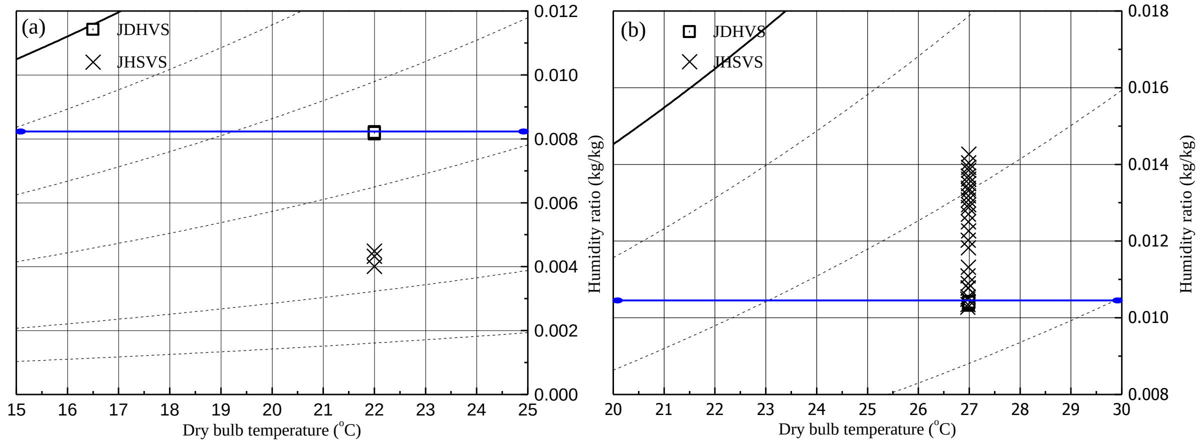

Figure 7. *Indoor conditions of two systems: (a) winter; (b) summer*

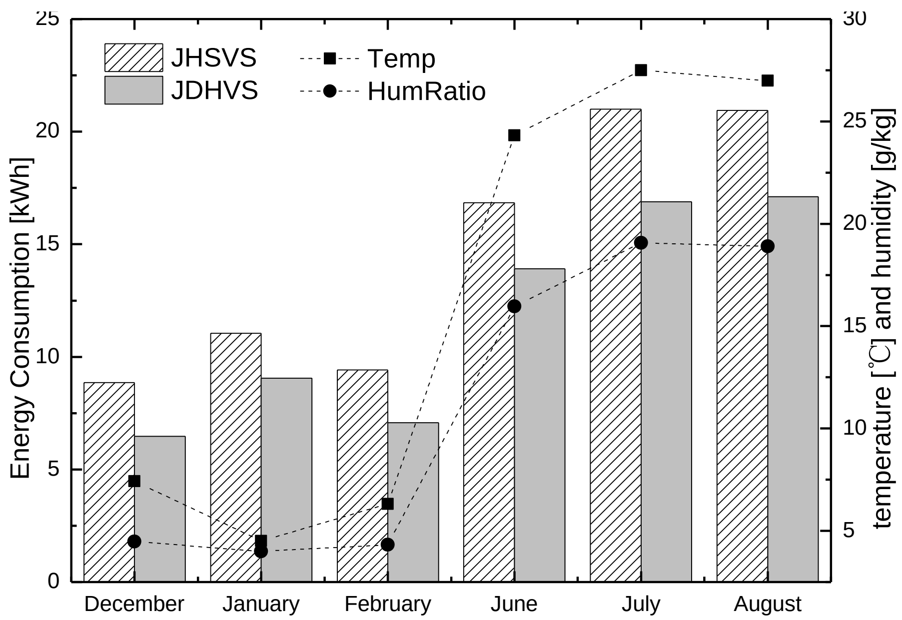

Figure 7. *Monthly energy consumption of two systems: (a) winter; (b) summer*

Fig. 8 shows the daily energy consumption in winter season and summer season, respectively with daily total data in each seasonal design day. It is found that through the whole winter season, energy saving can be achieved by JDHVS comparing to JHSVS. Specifically, DESICA system can save 27% in December, 18.1% in January, and 24.9% in February. In Fig. 8b, energy saving can be achieved in the whole summer season as well, while the ratio is 17.4% in June, 19.6% in July, and 18.3% in August.

CONCLUSIONS

In this study, a new module is developed in EnergyPlus, in order to evaluate the benefits of the novel JDHVS, integration of DESICA and HSHVRV, both performance and energy consumption. A case study is then made to perform a comparison of JDHVS and JHSVS in a real building in Shanghai. From the simulation results, the following conclusions are deduced.

- Compared to JHSVS, JDHVS has a better capability to keep the indoor humidity ratio at the target value of 50%, resulting in a better thermal comfort. Meanwhile, both systems can keep the indoor temperature at the target value of 27 ^{o}C.
- With the DESICA handling part of the sensible load, the cooperating HSHVRV of JDHVS can save much energy compared to the cooperating standard VRV of JHSVS.
- Overall, the joint DESICA and VRV system can save energy in the whole summer and winter season, specifically, 27% in December, 18.1% in January, and 24.9% in February for winter season and 17.4% in June, 19.6 % in July, and 18.3% in August for summer season.

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REFERENCES

N. Eskin, H. Turkmen, Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey, Energy and Buildings 40 (5) (2008) 763 – 773

W.Z. Huang, M. Zaheeruddin, S.H. Cho, Dynamic simulation of energy management control functions for HVAC systems in buildings, Energy Conversion and Management 47 (7 – 8) (2006) 926 – 943.

T.N. Aynur, Y. Hwang et al, Field performance measurements of a heat pump desiccant unit in dehumidification mode, Energy and Buildings 40 (2) (2008) 2141 – 2147.

T.N. Aynur, Y. Hwang et al, Integration of variable refrigerant flow and heat pump desiccant systems for the heating season, Energy and Buildings 42 (4) (2010) 468-476.

T.N. Aynur, Y. Hwang et al, Integration of variable refrigerant flow and heat pump desiccant systems for the cooling season. Applied Thermal Engineering 30 (8-9) (2010) 917-927.

Y.P. Zhou, J.Y. Wu, R.Z. Wang, S. Shiochi, Energy simulation in the variable refrigerant flow air-conditioning system under cooling conditions, Energy and Buildings 39(2) (2007) 212 – 220.