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Performance analysis of heat pump assisted desiccant cooling system through experiment

Tae-Ha Leigh [a], Se-Jin Lee [b], Chang-Ho Jeong [c], Myoung-Souk Yeo [d].

[a] Department of Architecture and Architectural Engineering, Graduate School, Seoul National University, Seoul, Korea, redsky2969@snu.ac.kr

[b] Department of Architecture and Architectural Engineering, Graduate School, Seoul National University, Seoul, Korea, qkqhtpwls@snu.ac.kr

[c] Division of Architecture for Urban Planning & Real Estate Development, The University of Suwon, Hwaseong, Korea, chjeong@suwon.ac.kr

[d] Institute of Construction and Environmental Engineering, Department of Architecture and Architectural Engineering, Seoul National University, Seoul, Korea, msyeo@snu.ac.kr

Abstract. The building heat resistance performance and air tightness are more and more developed. According to this, especially in hot and humid climate, the latent load easily increases and occupant comfort decrease. Because of this the importance of dehumidification grow higher and higher. Heat pump assisted desiccant cooling (HPDC) system is one of the systems to control the indoor humidity while using less energy than conventional condensation dehumidification and general desiccant cooling system by using condensation heat as regeneration heat for desiccant. And the disadvantage of HPDC system, which is hard to control the temperature, is supported by using radiant ceiling panel (RCP) to control the room temperature. The object of the paper is analyzing the energy performance and thermal comfort satisfaction of HPDC system and analyze the adaptability of HPDC system combined with RCP (HPDC w/RCP) through experiments. In experiment 1, HPDC system used 55% lower energy consumption compared to packaged air conditioning system (PAC) and can satisfy comfort zone rather than PAC system, especially in humidity comfort range. In experiments 2, HPDC w/RCP system satisfied ASHRAE comfort zone 12% more than HPDC system and used 5% lower energy. The experiment performed in this study can prove that the HPDC system is a possible alternative system of conventional cooling and dehumidification systems and HPDC w/RCP also has possibility to enhance the thermal comfort and energy saving.

Keywords. Heat pump assisted desiccant cooling system. Radiant ceiling panel. Dehumidification. Energy consumption. Thermal comfort.
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1. Introduction

As Passive house researches aim to get Zero Energy Building (ZEB) goes deeper and deeper, the insulation and air tightness performance grow better and better. For this growth, especially in hot and humid climate, latent load increase and satisfaction decrease are easily occurred. Also, the requirement of fresh outdoor air and changing lifestyle of occupants leads the increase of latent load ratio to total indoor load [1]. Besides, it was demonstrated that the growth of bacteria and melds affecting human health problem can be inhibited easily under 40~60% relative humidity conditions [2].

For above reasons, thermal discomfort due to increased humidity become main issue of indoor environment control because the conventional air-conditioning systems do not contain the effective dehumidification capacity. Condensation dehumidification is mostly selected method in conventional air-conditioning system due to the compactness and convenient maintenance. Subcooling and re-heating process to perform condensation dehumidification causes unnecessary energy consumption [3, 4]. Because of this, prior researches focused to desiccant systems, especially solid desiccant systems for their compactness compared to liquid desiccant systems. Heat pump assisted desiccant cooling system (HPDC) is the dehumidification and cooling systems using solid desiccant. Because this system uses condensation heat as regeneration heat for solid desiccant, it can reduce the need for regeneration heat source and also can control the zone humidity [3]. It was verified that the installation of cooling coil for pre-cooling in front of solid desiccant wheel increases the performance of dehumidification system [5]. However, when use this method, there is difficult at controlling the outlet temperature of the system because of the temperature increase while dehumidification. To solve this problem, there are two methods; one way is using cooling coil at front of desiccant wheel while stopping dehumidification, the other way is using other sensible heat control system like radiant cooling panel.

When using conventional air systems like packaged air conditioning (PAC) system, it consumes more energy than radiant ceiling panel (RCP). According to this research results, there has been researches applying RCP to the desiccant dehumidification system [6, 7]. It was announced that when using HPDC combined with RCP can satisfy users' comfort rather than when using PAC as cooling and dehumidification system [7].

In this paper, the performance of HPDC is analysed through experiment with comparative analysis between HPDC system and PAC system. Additionally, adaptability of HPDC w/RCP is also analysed through additional experiment compared with HPDC system.

2. Performance evaluation experiments

2.1 Experiment 1 (HPDC v.s. PAC)

HPDC is main target of the study and to confirm the possibility of HPDC, in experiment 1, comparative analysis was carried out between the HPDC system and conventional system (PAC). HPDC system used DX HP as heat source which is inside the HPDC system, and used air in laboratory (LA), maintained 26℃, and PAC system used electric heat pump (EHP) as heat source and used outdoor air (OA), which is 15℃ at the experiment period. Fig. 1 and Fig. 2 shows the schematic diagram of HPDC system and PAC system.

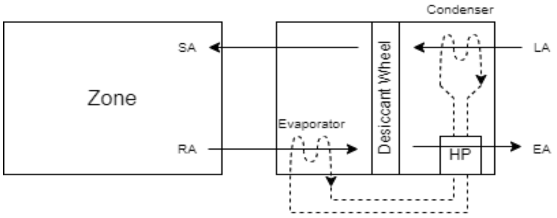

Fig. 1 – Schematic diagram of HPDC.

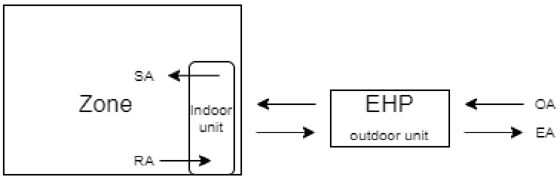

Fig. 2 – Schematic diagram of PAC.

2.2 Experiment 2 (HPDC v.s. HPDC w/RCP)

In experiment 2, adaptability of HPDC combined with RCP to resident building was analysed compared with HPDC system. When operate HPDC w/ RCP, LA also used as inlet air-source for the desiccant dehumidification and OA is used to produce chilled water used at RCP. Fig. 3 shows the schematic diagram of HPDC w/RCP. HPDC can control room air temperature and relative humidity by itself. But by using RCP, the energy use for cooling and dehumidification will be reduced and comfort also be increased.

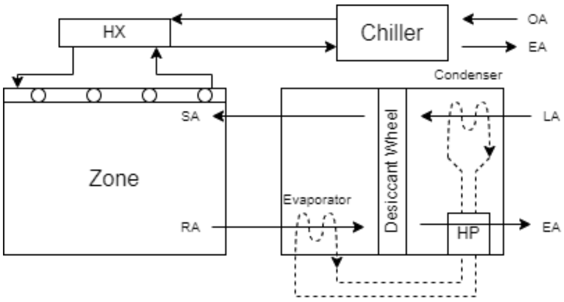

Fig. 3 – Schematic diagram of HPDC combined with RCP.

2.3 Experiment Criteria

Main target of the study is resident building in hot and humid climate (e.g. Seoul, South Korea). Considering this, the living room located at the inside part of the building was traced to the experiment chamber. Because the inside part of the building is traced, only internal heat gain was considered (especially the load due to people. Other loads like solar radiation and loads due to lighting and device were ignored).

Cooling and dehumidification are main subject of the study, cooling season is selected as experimental environment, Outdoor temperature is traced as 32℃ at the outdoor air chamber. The initial condition of chamber at experiment 1 is assumed as 28℃, 40%. At experiment 2, to discriminate the performance of HPDC system and HPDC w/ RCP system, which have very similar consistence, initial condition goes higher by 30, 80%, Set point temperature and set point relative humidity were selected as 26℃, 50% for each and temperature is prior control variable.

The number of occupants and internal load due to occupants were calculated according to floor area. To implement the internal load due to occupants, four 60W dummies consisted with light bulb to describe sensible load and one 157W humidifier to describe latent load were installed inside the chamber.

Both experiment 1 and experiment 2 were performed at the same environment conditions mentioned above (Tab. 1) for equality.

Tab. 1 – Experiment environment summary.

Criteria	Value
Chamber size	4.2 m x 5.5m x 3.0m
No. of Users	3.4 people
Sensible load	238 W
Latent Load	153 W
Sensible load Imitate	60 W dummy 4ea.
Latent load Imitate	157 W humidifier 1ea.
Chamber initial Temp.	30 ℃
Chamber initial Hum.	80 %
Set Temp.	26 ℃
Set Hum.	50 %

Experiment 1 was excuted during the autumn season (at average OA temperature 15). To get exact results, experiment 1 lasted 12 hours for each case to meet the stable room conditions. Experiment 2 was excuted during wintre season (at OA temperature -2). To simply confirm the adaptability of HPDC w/RCP, experiment 2 lasted 1 hours for each case to reach the set point temperature and set point relative humidity.

At each case, cooling and dehumidification systems were controlled only by on/off control to compare basic energy consumption and comfort which is not affected by specific control method. However, especially HPDC, to control the temperature and humidity only with the HPDC, HPDC was operated in cooling mode and dehumidification mode alternately. And inlet chilled water temperature (T_{CWS}) of RCP system was controlled with PI control**.**

Tab. 2 – Experiment cases.

Case	System	Heat Source	Control
Exp 1, Case 1	HPDC	Attached HP	Set point On/Off Dehumidification mode / cooling mode
Exp 1, Case 2	PAC	Air source EHP	Set Temp. On/Off
Exp 2, Case 1	HPDC	Attached HP	Set point On/Off Dehumidification mode / cooling mode
Exp 2, Case 2	HPDC	Attached HP	Set. Hum. On/Off
	RCP	Chiller	Set. Temp. On/Off T_{CWS} PI control

2.4 Evaluate methods

To evaluate the energy usage of PAC and HPDC, power meter was use to log the electric energy use. And to estimate the energy use at chiller for RCP, heat removed by radiant panel and chiller COP was used as equation.

$$Q_{chiller} = (T_{CWR} - T_{CWS})\dot{m}_{CW}/COP_{chiller} \quad (1)$$

Fig. 4 – Experiment facilities. (a) indoor chamber. (b) HPDC system. (c) PAC system. (d) RCP. (e) chiller for RCP. (f) 60W light bulb dummy for sensible load trace. (g) 157W humidifier for latent load trace.

And to evaluate the thermal comfort, comfort zone announced at ASHRAE 55 was used. The operative temperature and humidity ratio data of each case were scattered in psychrometric chart and discriminated whether the data was inside the comfort zone or not. The satisfaction of occupants' thermal comfort was expressed with comfort zone satisfaction ratio as can confirm at equation (2).

$$\frac{(The\ number\ of\ data\ at\ the\ comfor\ zone)}{(Total\ number\ of\ data)} \qquad (2)$$

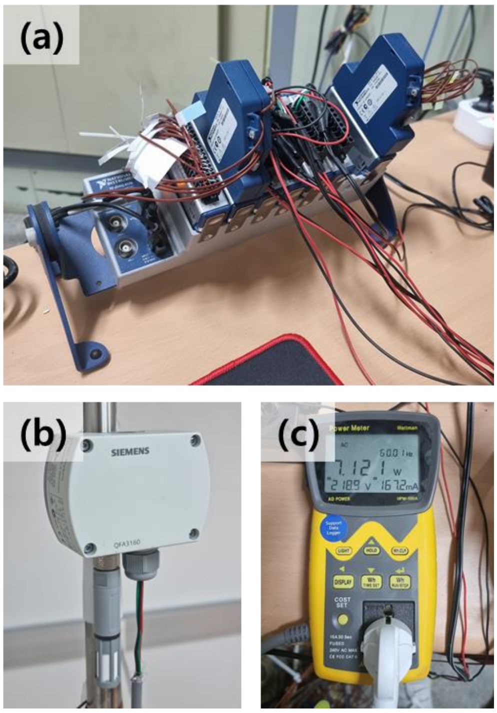

Fig. 6 – Sensors. (a) NI device for data collector and data transmission. (b) Relative humidity data logger. (c) Power meter.

3. Experiment Results

3.1 Thermal Comfort

Fig. 7 and **Fig. 8** shows the comfort distribution of the experiment 1.

The results show that Exp 1 Case 1, which used HPDC system controlled the temperature and humidity almost perfectly. There were no data which not satisfy the humidity range and just about 5.8% of data were dissatisfied the temperature comfort range.

Exp 1 Case 2, which used PAC system controlled not perfectly as HPDC. Lots of data were not inside the comfort zone. About 72.9% of data did not satisfy the humidity comfort range, only 0.8% of data did not satisfy the temperature comfort range in contrast.

With both results, the fact that HPDC system can control the indoor environment more perfectly in aspect of totally (temperature and humidity). However, as focus on temperature only, PAC system can control even more perfectly than HPDC system. On the other hand, PAC system also could not control the humidity well.

Through **Fig. 9** and **Fig. 10** shows the comfort distribution of the experiment 2.

The results show that Exp 2 Case 1, which used HPDC system mostly dissatisfied comfort zone because of the high initial condition and short experiment time. This is because, as designed, the experiments were carried out to just reach the set point and aim to confirm the reach speed. About 62.5% of data dissatisfied the temperature comfort range and 19.6% of data were dissatisfied the both temperature and humidity comfort range. Total 17.9% of data were satisfied comfort zone.

Exp 2 Case 2, which used HPDC w/RCP system also mostly dissatisfied due to the same reason of Exp2 Case 1. About 60.6% of data did not satisfy the temperature comfort range, and 11.5% of data were dissatisfied the both temperature and humidity comfort range. Total 27.9% of data were satisfied comfort zone.

With both results, HPDC w/RCP system can reach the comfort zone faster than HPDC system. And HPDC w/RCP can control the temperature better than HPDC system, according to the number of data satisfied the temperature comfort range. Thus, there is a possibility to adapt HPDC w/RCP system to resident building to get faster and better thermal comfort.

3.2 Energy Consumption

Energy consumption of each case can be found in **Fig. 11** and **Fig. 12.** Mentioned above, the energy consumption of PAC system and HPDC system were measured by power meter (**Fig. 6 (c)**). And the energy consumption of chiller used to make chilled water for RCP system were calculated by equation (1), which need the inlet and outlet temperature of chilled water used as RCP system. When calculate the energy consumption of chiller, the heat loss at distribution systems were ignored.

The energy consumption of Exp 1 Case 1 was much lower than Exp 1 Case 2 by 55%. Due to the energy wasted to perform subcooling and re-heating, PAC system consume much more energy than HPDC system.

The energy consumption of Exp 2 Case 1 was little bit higher than Exp 2Case 2 by 5%. HPDC system perform the cooling and dehumidification by itself using cooling mode and dehumidification mode alternatively. HPDC w/RCP system additionally used RCP for cooling compared to HPDC. HPDC system cools indoor air by convection using cooling coil.

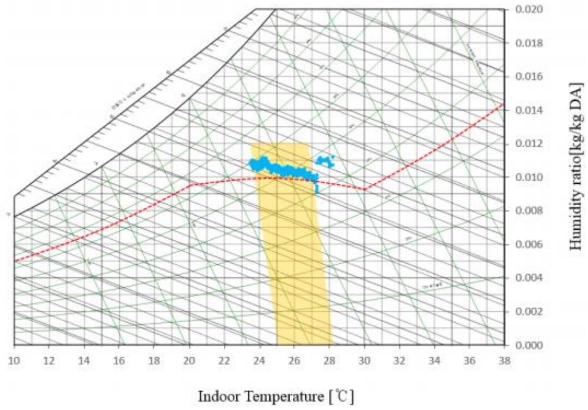

Fig. 7 – Comfort distribution of Exp 1, Case 1 data

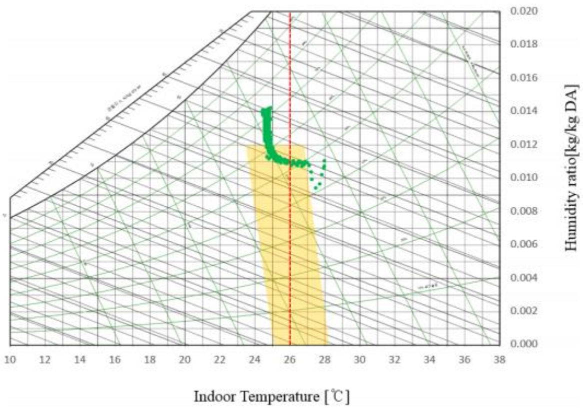

Fig. 8 – Comfort distribution of Exp 1, Case 2 data

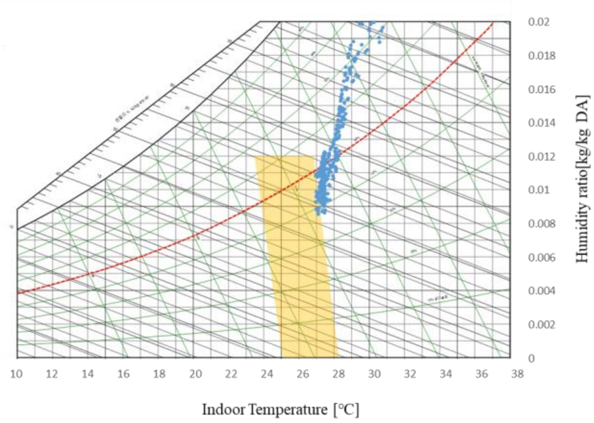

Fig. 9 – Comfort distribution of Exp 2, Case 1 data

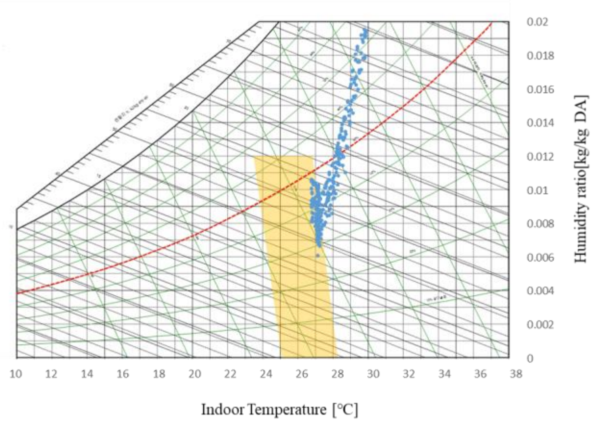

Fig. 10 – Comfort distribution of Exp 2, Case 2 data

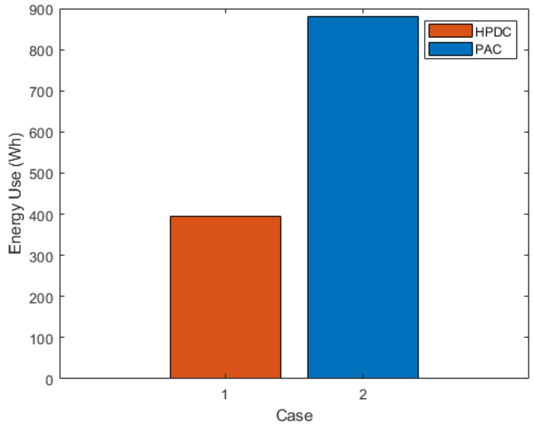

Fig. 11 – Energy consumption in Exp 1

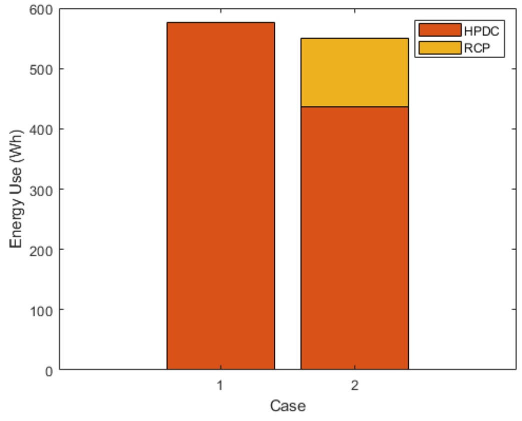

Fig. 12 – Energy consumption in Exp 2

And to be used at cooling coil for cooling mode, refrigerant inside the attached HP need to be cooled to temperature ranged at 7℃. However, when use RCP for cooling, sensible heat removed by radiation and, for that, the chilled water send to the RCP system does not need to be low temperature; it needs to be just 18℃. To make the 18℃ chilled water by heat exchanger between chiller and RCP, chiller only needs to make chilled water temperature at 12℃, which is much higher temperature than HPDC system. The difference between the temperature of evaporator side needed to be produced leads to the difference of energy consumption between Exp 2 Case 1 and Exp 2 Case 2.

4. Conclusions

In this study, performance of HPDC w/ RCP was evaluated by experiment and analysed with comparative analysis with PAC system and HPDC system. Results are follows.

(1) Shown in experiment 1 results (**Fig. 7, 8, 11**), using HPDC system has lower frequency which are at the outside of ASHRAE comfort zone rather than PAC system. When using HPDC system, the non-comfort data (about 5.8% of data) were at out of comfort temperature range and there were no data out of comfort humidity range. And at the view of energy consumption, HPDC system used much less energy compared to PAC system by 55%.

(2) Shown in experiment 2 results (**Fig. 9, 10, 12**), using HPDC system combined with radiant ceiling panel can reduce the energy consumption by 5% compared to HPDC system used case. Furthermore, data of HPDC combined with RCP, which located at outside of ASHRAE comfort zone, is less than data of HPDC system by 12%. This means that using HPDC combined with RCP has possibility to be used for energy saving and thermal comfort.

(3) The experiment performed in this research is carried out during the autumn and winter season in Seoul, South Korea. However, the verification targets were cooling systems, Therefore the outdoor air temperature used at experiments were not suitable to exact comparative analysis because some heat sources (PAC system and chiller for RCP) uses outdoor air. For more exact and reasonable evaluation, experiment during the cooling season (summer) should be performed in further study.

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