A study on reducing the energy demand of a liquid desiccant dehumidifier with a radiant panel system

Tae Ha Leigh,[1] Dae Uk Shin,[1] Goo Sang Joe,[1] Min Gi Kim,[1] Myoung Souk Yeo,[2] and Kwang Woo Kim[2,*]

[1]Department of Architecture and Architectural Engineering, Graduate School of Seoul National University, Seoul 151-744, Republic of Korea
[2]Department of Architecture and Architectural Engineering, College of Engineering, Seoul National University, Seoul 151-744, Republic of Korea

ABSTRACT

In hot and humid regions, cooling load and latent load should be removed together. Recently, liquid desiccant dehumidification is suggested as an efficient method of latent load removal. However, for continuous liquid desiccant dehumidification, liquid desiccant should be regenerated and regeneration heat is required.

In this study, radiant panel system is suggested as a cooling method. And a method to utilize the generated heat, during the chilled water making for radiant cooling system, for the regeneration of liquid desiccant is suggested. For the evaluation of the suggested method, the energy demands were simulated and compared.

As a result of comparison analysis between the energy demands of the system that uses suggested method and system that uses liquid desiccant dehumidifier and radiant panel separately, 85% of energy demand for regenerating liquid desiccant was reduced and 35% of energy demand for producing chilled water needed in cooling was reduced when using suggested method. Totally 63% of energy demand of the system was reduced.

Method to utilize the generated heat, during the chilled water making for radiant cooling system, for the regeneration of liquid desiccant will be very useful at hot and humid region that need cooling and dehumidification.

KEYWORDS

Desiccant regeneration, Latent load, Liquid desiccant dehumidification, Radiant panel

INTRODUCTION

Radiant panel systems offer several advantages including a moderate set temperature, thermal comfort, and lower energy use compared with air handling unit (AHU) systems. However, using a radiant panel system risks producing condensation on the panels, and it is difficult to remove this moisture, especially during dominant cooling

[*]Corresponding author email: snukkw@snu.ac.kr

seasons in regions with hot, humid climates. For this reason, a dehumidification system with a radiant panel system needs to be developed. In a former study performed by Niu et al. (2002), the energy-saving potential of a chilled ceiling combined with desiccant cooling was investigated. A desiccant wheel was used in the study. The study found that a desiccant wheel can solve the problem of latent load removal, and heat exchange between intake air and exhaust air can recover some heat in order to reduce energy demand.

Liquid desiccant dehumidification is one of the dehumidification methods used nowadays. Because it needs a relatively low temperature to regenerate the liquid desiccant then solid desiccant, a liquid desiccant dehumidifier has the potential to be suitably adapted to the buildings. A liquid desiccant dehumidifier is usually divided into dehumidification unit and regeneration unit. The process of dehumidifying air by the desiccant occurs in the dehumidification unit. The process of dehydrating the desiccant occurs in the regeneration unit. Regeneration heat is needed for this process. In a former study performed by Zhang et al. (2012), the methods for heat-pump-driven liquid desiccant dehumidification systems (HPLD) were introduced and analyzed by the optimization method. In the study, hot heat needed in regeneration and cool heat needed in dehumidification are used in the heat pump. By using the heat pump instead of the heater and chiller, the energy demand of the liquid desiccant dehumidifier for regenerating the liquid desiccant is decreased.

When using a radiant panel in dominant cooling seasons, the hot heat in the returned chilled water is removed. In a former study conducted by Shin et al. (2012), hot heat from the returned chilled water was used to make domestic hot water. In this study, a liquid desiccant dehumidifier was used, and the hot heat from the returned chilled water was supplied as the regeneration heat for the liquid desiccant dehumidifier.

In this study, a method to reduce the energy use of liquid desiccant dehumidifiers with a radiant panel system (RPLD) is suggested, and the applicability of the method is evaluated by analyzing the energy use of the method using the system.

RESEARCH METHODS

To suggest a method to reduce the energy demand of the RPLD, the load-removing processes of the RPLD and the system construction need to be understood. To evaluate the applicability of the method to reduce energy for RPLD, the system’s total energy use should be known. Then, the energy demand of the RPLD using suggested method and the energy demand of the RPLD without using this method should be compared.

Load-removing processes of RPLD

The load-removing process of the RPLD can be divided into three subprocesses: (1) the dehumidification process; (2) the regeneration process; and (3) the cooling process. The dehumidification process and regeneration process are the processes to remove the latent load and the cooling process is the process to remove cooling load.

The dehumidification process includes the dehumidification unit of the liquid desiccant dehumidifier. During this process, inside air that should be treated will be passed through the scattered desiccant drops, and the moisture in the air will be absorbed by the desiccant. During this process, the lower the temperature of the desiccant, the higher the moisture removal rate (ASHRAE 2012). To decrease the temperature of the desiccant, cool heat is needed, and producing this cool heat demands energy.

The regeneration process includes the regeneration unit of the liquid desiccant dehumidifier; this is the process that regenerates the desiccant, which is continuously used in the dehumidification process. The outside air (or exhaust air) will pass through the diluted desiccant and dehydrate the desiccant. To dehydrate the desiccant, regeneration heat is needed. This regeneration heat also demands energy to be produced.

The cooling process occurs in the radiant panel. During this process, the radiant panel removes the cooling load in the zone with the chilled water. Energy is also needed to produce the chilled water.

Method for reducing energy use of RPLD

The RPLD consists of a radiant panel, a liquid desiccant dehumidifier, and an auxiliary heater. The radiant panel removes the cooling load, and the liquid desiccant dehumidifier removes the latent load. The auxiliary heater supplies the regeneration heat, which is needed to dehydrate the desiccant so that the desiccant can be used again. Figure 1 shows the construction and operating method (Method 1) of the RPLD and the energy use in each process.

Method 2 reduces the energy demand of RPLD by using the method that supplies the regeneration heat with the generated heat during the chilled water making for radiant cooling system. In this system which uses Method 2, the regeneration process and cooling process are combined. Regeneration heat is supplied as hot water (approximately 45–55°C). Heat pump is used for cooling the returned chilled water from cooling process and remained generated heat, during the chilled water making for radiant cooling system, is supplied to regeneration heat medium. Supplying regeneration heat uses lower energy with this method then with auxiliary heater.

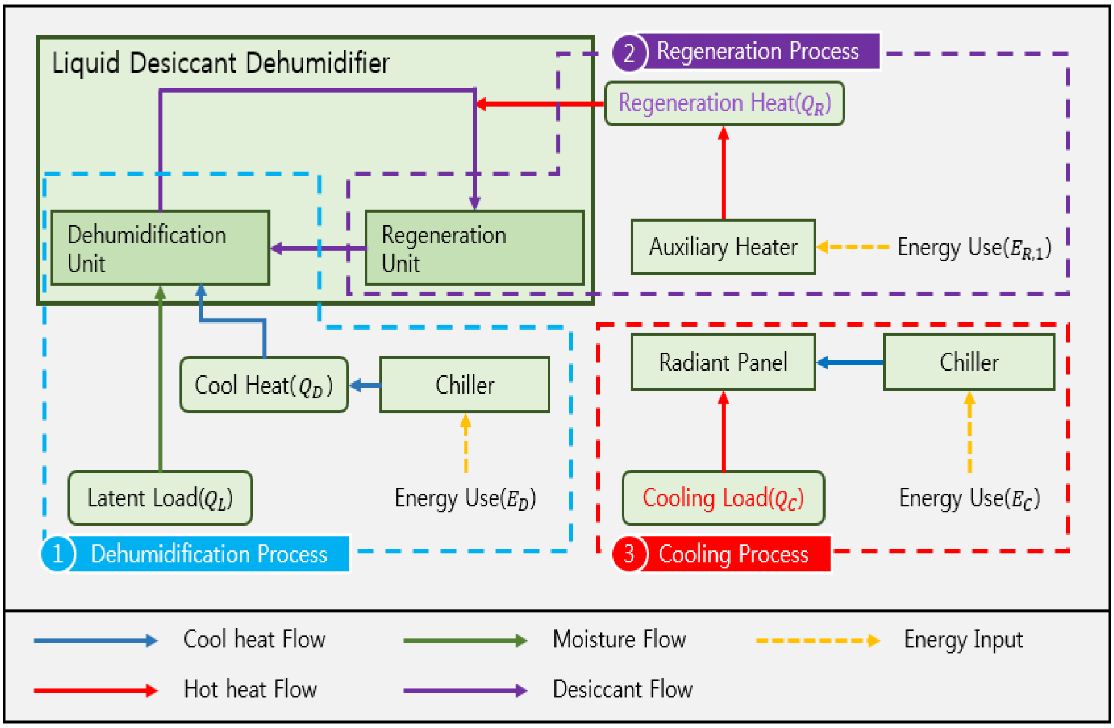

Figure 1. *Schematic diagram of Method 1*

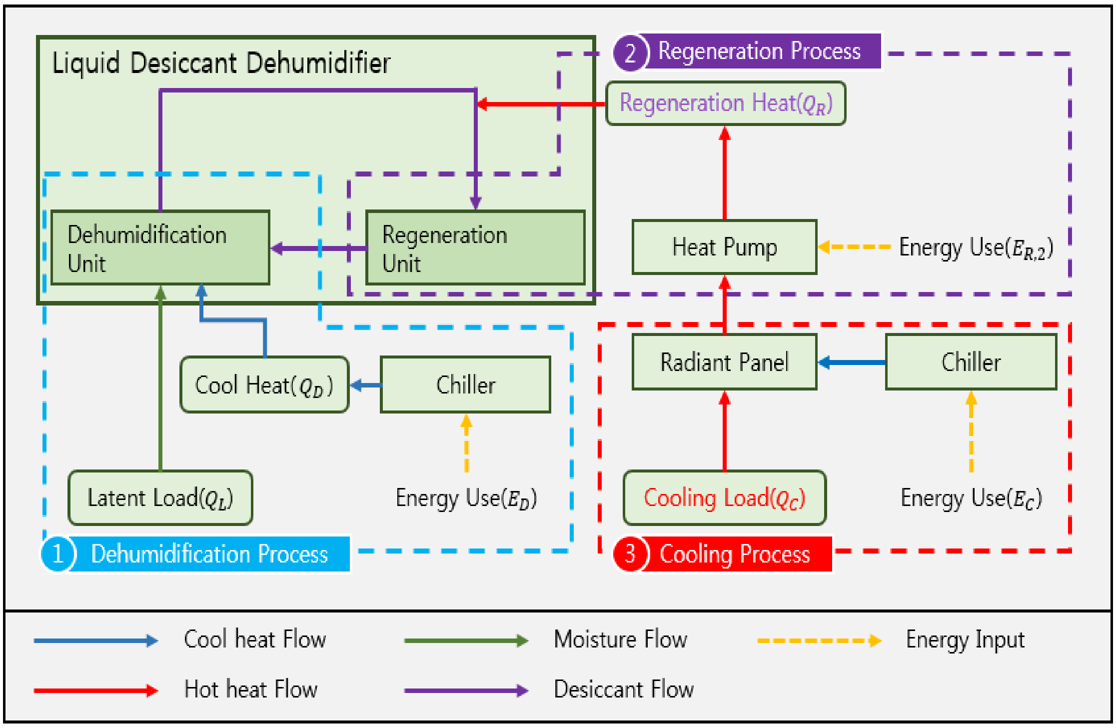

Figure 2. *Schematic diagram of Method 2*

Methods 1 and 2 are almost the same, except that regeneration heat needed in the regeneration process is produced by the auxiliary heater in Method 1 and by heat pump in Method 2 (Table 1). Therefore, only the regeneration processes which have difference between two methods should be compared.

Table 1. Energy use of Methods 1 and 2

	Method 1	Method 2
Dehumidification process	Energy demand for producing chilled water used for chilling the desiccant to raise the efficiency of desiccant dehumidification (E_D)	
Regeneration process	Energy demand to generate heat for liquid desiccant regenerating with auxiliary heating device ($E_{R,1}$)	Energy demand to generate heat for liquid desiccant regenerating with heat pump ($E_{R,2}$)
Cooling process	Energy demand to produce chilled water by chiller (E_C)	

Comparative study

To evaluate the applicability of Method 2, a comparative analysis should be performed. Because the dehumidification processes are same, the energy demands at dehumidification process of Methods 1 and 2 are same. Therefore, just the energy demands of Methods 1 and 2 at regeneration process and cooling process which is changed as the regeneration process is changeed should be compared.

For a precise comparison, both methods should be simulated in the same condition. If they are in the same condition, the loads occurring in the zone are also the same. To evaluate the applicability, the energy demand of both methods should be calculated. In order to calculate this demand, the cooling loads and latent loads of the zone should be simulated. The conditions and loads are simulated by TRNSYS 17 (Klein et al. 2010). The simulation input data in this case are described in Table 2.

***Table 2**. Simulation input data*

Location	Seoul, Republic of Korea
Period	Three months (June 1–August 31)
Area	72.9 m^2
U-value of wall/window	North window: 1.4 W/m^2K East/west/south/north wall: 0.254 W/m^2K Ceiling (radiant cooling): 0.179 W/m^2K Floor: 0.266 W/m^2K
Set temperature	26°C
Set relative humidity	40%
Schedule	Monday–Friday: workday (8:00–18:00: 100%/other: 0%) Saturday–Sunday: weekend (0:00–24:00: 0%) Heat gain from people (sensible): 65 W/person Heat gain from people (latent): 55 W/person Heat gain from equipment: 230 W/each Heat gain from lighting: 5 W/m^2

The data from the former study performed by Zhang et al. (2012) were used in the calculations. The data include the temperature and humidity of the desiccant during each process and the coefficient of performance (COP) of the heat pump at each temperature of the heat sources. The ratio between the removed latent load and the regeneration heat was derived from the data. The regeneration heat was calculated using the ratio and the latent load from the simulation. After this calculation, the energy demand in the heat pump was calculated. Returned regeneration heat medium was used as the high temperature heat source for the heat pump, and the chilled water return from the radiant panel was used as the low temperature heat source for the heat pump. The heat pump COP that is suitable for the suggested method for the RPLD was selected. These data are described in Table 3.

***Table 3**. Input data for energy demand calculation*

Input data	Value
Regeneration heat medium (high temperature heat source) (°C)	42.6
Chilled water return (low temperature heat source) (°C)	15.4
Ratio of regeneration heat to removed latent load	1.2
COP of heat pump	5.68
COP of chiller	3

RESULTS AND DISCUSSION

The simulation data are shown in Figure 3. The figure shows the cooling load, latent load, and energy demand of the chiller to remove cooling load in Method 1; the energy demand of the chiller to remove latent load in Method 1; the energy demand of the auxiliary heater to remove latent load in Method 1; the energy demand of the chiller to remove cooling load in Method 2; the energy demand of the chiller to remove latent load in Method 2; and the energy demand of the heat pump to remove latent load in Method 2. The data were analyzed over 1 week for 3 months.

The simulation shows that the cooling load is larger than the latent load every week in this case. It means that it is possible to supply regeneration heat with the generated heat, during the chilled water making for radiant cooling system. The energy demand of the chiller to remove latent load in Methods 1 and 2 are same. Method 1 uses the chiller to remove the hot heat in the returned chilled water and an auxiliary heater to supply regeneration heat. However, Method 2 uses the generated heat, during the chilled water making for radiant cooling system as regeneration heat. After operating heat pump, if more chilling is needed for chilled water, air source heat pump used in Method 1 is used. The results (Figure 3) show that the energy demand of Method 2 is lower than the energy demand of Method 1 overall.

Table 4 shows the loads and energy demand of each process over 3 months. The energy demand of the RPLD in the regeneration process decreased approximately by 85% when using Method 2. The energy demand in the cooling process (E_C) also decreased by approximately 35% using this method in this case. Overall, energy demand was reduced by 63% over 3 months.

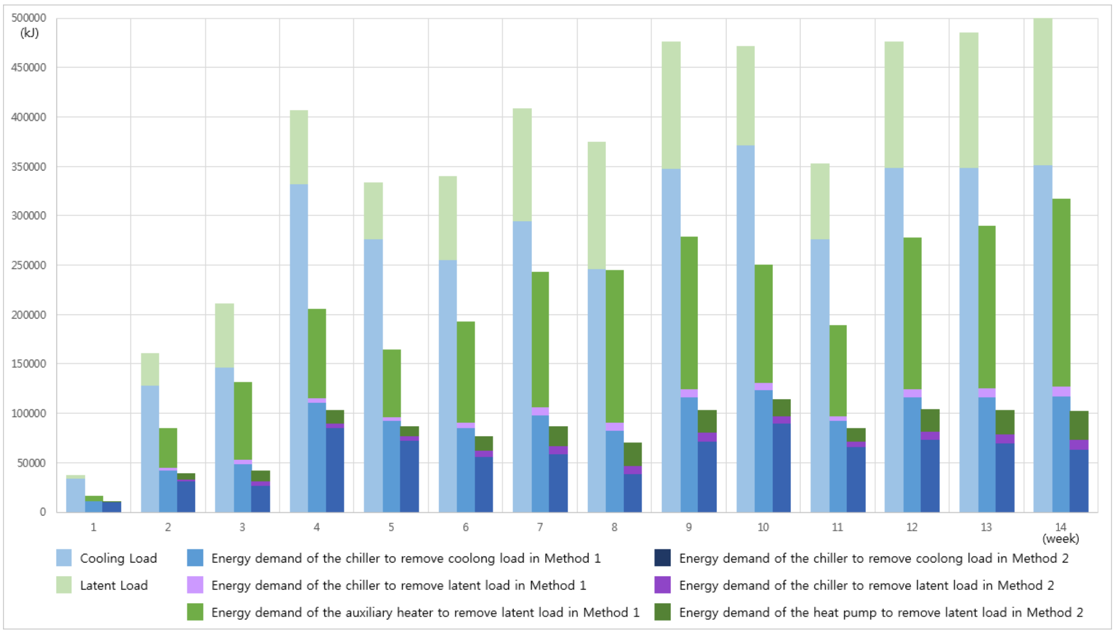

Figure 3. *Zone loads and energy demand of Methods 1 and 2*

Table 4*. Sum of loads and energy demand over 3 months*

Load		Energy demand					
		Method 1			Method 2		
		Air source Chiller (dehumidification process)	Auxiliary heater (regeneration process)	Air source Chiller (cooling process)	Air source Chiller (dehumidification process)	Heat pump (regeneration process)	Air source Chiller (cooling process)
Cooling load	3,753,370	—	—	1,251,123	—	273,173	824,973
Latent load	1,293,021	86,201	1,551,625	—	86,201		—
Total	5,046,391	2,888,950			1,129,822		

Note: Units are in kJ.

CONCLUSIONS AND IMPLICATIONS

In this study, the applicability of a liquid desiccant dehumidifier with a radiant panel system was evaluated with a method for reducing the energy demand of an RPLD. For evaluation, the load-removing processes and construction of an RPLD were analyzed, and the standard and suggested methods for RPLD were compared. The conclusions of this study are as follows:

(1) The method to reduce the energy demand of the RPLD uses a heat pump instead of an auxiliary heater to replace the regeneration heat supply with the generated heat during the chilled water making for radiant cooling system.
(2) When using the suggested method (Method 2), energy demand is reduced during two of three processes of liquid desiccant dehumidification. In the regeneration process, instead of supplying regeneration heat by a heater (Method 1), the generated heat, during the chilled water making for radiant cooling system, is supplied (Method 2). The energy demand in the regeneration process decreased by 85%. In the cooling process, hot heat in the chilled water return after cooling the zone is removed by an air source chiller (Method 1). However, when using Method 2, 35% of hot heat in returned chilled water is removed by the using additional water-to-water heat pump for regeneration heat supply. Energy demand can be reduced by 35% in the cooling process. Overall, when using Method 2, energy demand of the RPLD can be reduced by approximately 63%.
(3) This study shows that by using the suggested method for an RPLD, the latent load problem when using a radiant panel can be solved. This method can also reduce energy demand in the regeneration and cooling process. These results will be useful for buildings in regions with hot, humid climates.

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