Feasibility of a Liquid Desiccant Application in an Evaporative Cooling Assisted 100% Outdoor Air System

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ABSTRACT

Of the components of a liquid desiccant system in an evaporative cooling assisted 100% outdoor air system (LD-IDECOAS), liquid desiccant is the only active system that conditions the supply air. However, the liquid desiccant solution that is heated for regeneration should be cooled to prevent heat transfer from the solution to the process air. This paper introduces the operation of only the cooling tower without a chiller to cool the liquid desiccant solution. The thermal performance and energy saving potential of the cooling tower employed in the proposed system were estimated via a conventional VAV system. For the conventional VAV system, the conventional vapour compression refrigerator, which is composed of a chiller and cooling tower, was assumed to be applied to the cooling of process air. In order to evaluate the cooling energy consumption during the cooling season, the proposed system was modeled using the TRNSYS 16 energy simulation program. The cooling tower capacity and performance data were obtained from the manufacturer. In order to simulate the solution heating process, RETscreen is also used to estimate the performance of solar thermal system for solution heating source.

The simulation results showed that the cooling tower can be operated without the chiller allowed to serve higher cooling water temperature for cooling the liquid desiccant solution. Although the outlet water temperature of the cooling water did not attain the targeted value when the weather was too humid, one might show that the liquid desiccant solution was generally maintained at a target temperature of 30C. This problem did not significantly affect the thermal performance of the proposed system. The cooling energy demand for LD-IDECOAS using only the cooling tower was reduced by 52-59% relative to the conventional VAV system.

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KEYWORDS
Cooling tower, evaporative cooling system, liquid desiccant system, 100% outdoor air system

INTRODUCTION

There is growing interest in energy saving buildings and healthy indoor environments. Many studies have also examined the usage of renewable energy and performance enhancement of HVAC systems. Recently, studies on cooling systems have successfully used the latent evaporative heat of water to reduce the conventional cooling coil load (Kim et al. 2011a, Kim et al. 2011b). However, the cooling performance of indirect and direct evaporative coolers may not significantly reduce the conventional cooling coil load.

In order to overcome this limitation, interest has grown in applying a liquid desiccant system to an evaporative cooling system to enhance the performance. Since the regeneration of desiccant requires low-grade energy, solar energy and sources from waste heat can be deployed. Cooling energy is also required for the solution in order to restrict the heat transfer between the heated solution and process air.

Many studies have examined desiccant-based air-conditioning systems integrated with solar energy, which is an unlimited free source of energy. However, research on the solution cooling source is very rare; a conventional refrigerant-based cooling coil is used as the solution cooling source.

This paper proposes the the application of a solution cooling plant to liquid desiccant in an evaporative cooling assisted 100% outdoor air system. In order to configure the solution cooling plant, operation of the cooling tower without the conventional chiller was implemented using the TRNSYS 16 program. A solar thermal collector was also employed in the proposed system to control the solution heating load. The system was analysed by using the RETscreen program. The energy saving potential of the proposed system relative to a conventional variable air volume (VAV) system was quantitatively evaluated comparing cooling energy consumptions for both systems during the cooling season (i.e. July and August).

LIQUID DESICCANT IN EVAPORATIVE COOLING ASSISTED 100% OUTDOOR AIR SYSTEM

(1) System configuration

As shown in Figure 1, our proposed system is composed of a liquid desiccant (LD), indirect evaporative cooler (IEC), and direct evaporative cooler (DEC) on the process air side. A heating coil (HC) and sensible heat exchanger (SHE2) are located on the exhaust air side of the system. A double duct or multizone system is used to handle difference thermal environment demands for each room. The process air volume is adjusted depending on load variation, as in a VAV system. Depending on the selected configuration, an additional sensible heat exchanger (SHE1) can be applied before the LD upstream.

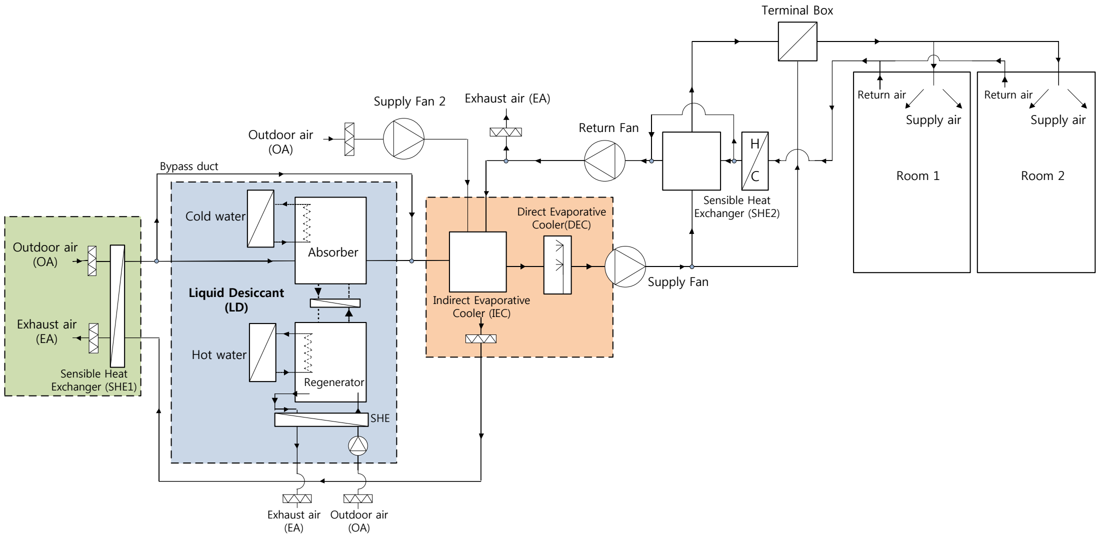

Figure 1. *Schematic of desiccant and evaporative cooling assisted 100% outdoor air system*

(2) Liquid desiccant operation

The liquid desiccant system in this study was composed of a regenerator, absorber, SHE3, heating source, and cooling source. The liquid desiccant solution is cooled by a cooling source. The air supply is then dehumidified by the cooling solution. The target heating temperature of the solution is maintained by a heating source for regeneration. A solution diluted in the absorber is concentrated in the regenerator. When SHE3 is located between the regenerator and the absorber, the solution cooling and heating load can be effectively reduced.
In a liquid desiccant system, heat and moisture are transferred between the desiccant and air via the vapour pressure difference. For regeneration, the solution should generally be heated to 45-80C, after which is cooled to 15-30C for dehumidification. This process requires solution cooling and heating load.

(3) Strategies for solution cooling and heating

Many studies have examined ways to maintain the target heating temperature. When the heating source is obtained by renewable energy, which is easy to obtain during the cooling season, such as by solar thermal systems, additional heating system based on electricity or gas is not necessary.
However, an electricity-based cooling plant is required for the solution cooling load. The specific heat of the LiCl solution is lower than that of water (i.e. LiCl = 2.6 kJ/kgC, water = 4.19 kJ/kgC); thus, the solution should be able to be cooled with only the cooling tower without a chiller. Because the solution may not require reducing the supply air temperature in the proposed system, the solution can attain a temperature of 25-30C with operation of only the cooling tower.

ENERGY SIMULATION

(1) Outline of model building

The model building was an office building with a floor area of 7500 m2 and 800 occupants. Each occupant was assumed to have a personal computer and do light work according to ISO-7730; the sensible heat was 75 W/person, and the latent heat was 75 W/person. The light density was 13 W/m^2. The office building was regularly used from 7 AM to 10 PM for 5 days a week. The heat transfer coefficient (i.e. U-value) of the exterior wall was assumed to be 0.511 W/m2C, and that of the roof was assumed to be 0.316 W/m^2C. The window-to-wall ratio was 0.25. In this simulation, the indoor temperature is set to 24C for cooling, 20C for heating. Because the space latent load is limited, target supply air temperature in cooling season was set to 13C which is dew-point temperature of indoor conditions (24C, 50%). In order to prevent the increase of indoor heating load by required ventilation rates, the supply air temperature was set to 20C in the heating season.

In order to estimate the performance during the cooling season, the operating energy consumptions of the proposed system and VAV system were evaluated. These models were simulated using TMY2 weather data for Seoul, Korea.

(2) Operating conditions of the proposed system

The major components of the proposed system were the LD, IEC, and DEC. In the proposed system, the process air condition is maintained mainly by modulating the solution flow rates of the LD. The process air is then conditioned by passing it through the IEC and DEC in series. When it is difficult to maintain the target supply air temperature, additional cooling can be achieved by installing SHE1.

The liquid desiccant system of the proposed system is composed of an absorber, SHE3, regenerator, cooling source, and heating source. The effectiveness of the reported components, used in the simulation to evaluate the LD performance, is obtained from open literature (Jain et al. 2011, Gommed and Grossman 2007, Kim et al. 2011b, Wetter 1998, Wu et al. 2009).

Dehumidification rate is controlled by using the liquid-to-gas ratio (L/G ratio) in order to control the target supply air temperature(i.e. 13C). In this simulation, L/G ratio was modulated from 0.6 to 1. In order to maintain the dehumidification rates and prevent heat transfer to the supply air, a solution inlet temperature setpoint of 30C was maintained by the cooling source.

The operating performance of the proposed system was affected mostly by the heating solution temperature for regeneration. The heating temperature of the solution affects the solution cooling load as well as the effectiveness of regeneration. In this study, two regeneration temperatures were employed for the liquid desiccant system and simulated: 60C (CASE 1) and 45C (CASE 2).

(3) Operating conditions of VAV system

The supply air flow rate was controlled according to the indoor sensible heating load; 20% of the outdoor air was used for ventilation. The supply air temperature setpoint of 13C was maintained by the cooling coil. An air side economizer was also adopted.

When the enthalpy of the outside air was lower than that of the exhaust air and the dry-bulb temperature of the outside air was more than 13C, the return damper was closed and the 100% outdoor air was induced.

(4) Design of chilled water plants

The solution cooling plant was composed of a single cooling tower, single heat exchanger (SHE5), and pump for the cooling tower. The energy consumptions of the fan and pump can be effectively reduced by providing a variable frequency drive (VFD). The TRNSYS 16 simulation program with a type 51 cooling tower was used to simulate the solution cooling plant.

For the conventional VAV system, the supply air temperature through the cooling coil becomes 13C through operation of a single chiller and cooling tower. The flow rates of the water and refrigerant are controlled by tuning the cooling load.

(5) Design of solution heating plant

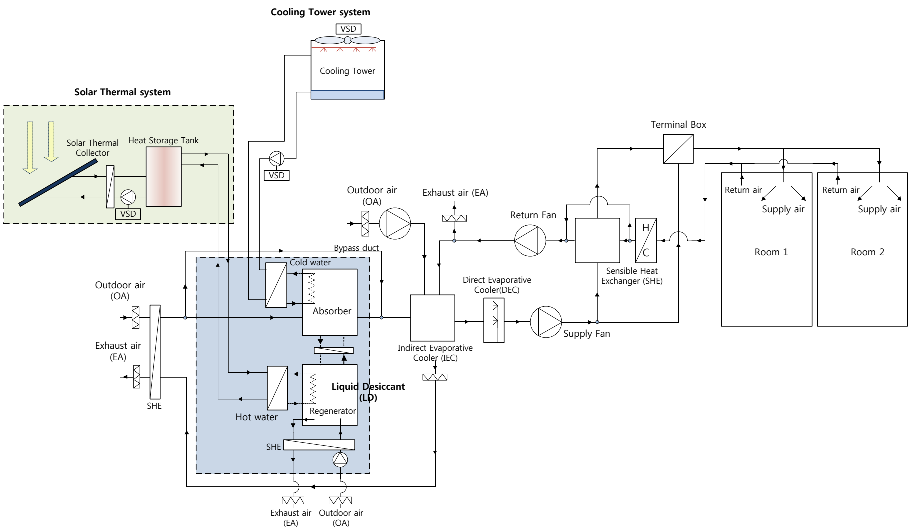

Figure 2. *Solar thermal collector plant*

Liquid desiccant, which is one of the components of the proposed system, requires a solution heating load for solution regeneration. There are various heating sources; a solar thermal collector is one of the simplest and most effective alternatives to the typical electric heater. In order to heating the desiccant solution for regeneration in this study, a solar collector was assumed to be the heating source. As shown in Figure 2, a solar thermal collector plant is composed of a solar thermal collector, heat exchanger, and storage tank. The target solution heating temperature was set by following CASE 1 and CASE 2. The solution temperature was raised by heating water with a heat exchanger (SHE4). The fixed tracking mode and evacuated type solar thermal collector was assumed to have a 45° slope angle and 0° azimuth angle. Each solar collector had a gross area of 3 m^2. A storage tank with a 75 L/m^2 capacity per solar collector's area and a heat exchanger with 70% effectiveness were also used. The pump power was set to 8 W/m^2 as a typical value.

SIMULATION RESULTS

(1) Comparison of cooling load

The cooling coil load of the conventional VAV system and solution cooling load of the proposed system were simulated during the cooling season (i.e. July and August). The CASE1 of the proposed system showed a peak solution cooling load that was 29.1% higher than that of CASE 2 of the proposed system. The higher solution cooling load in CASE 1 was attributed to the higher solution heating temperature for regeneration.

For the proposed system in CASE 1, the peak solution cooling load increased by 41% and the total solution cooling load during the cooling season also increased by 23% with respect to the conventional VAV system. In CASE 2, the peak and total solution cooling loads increased by 63% and 56%, respectively. Because the goal of using the solution cooling load is to reduce the temperature of the liquid desiccant solution, which has a high specific heat (i.e. 2.6 kJ/kg K), and that of cooling coil load of the VAV system is to cool the air (i.e. specific heat is 1.01 kJ/kg K), the solution cooling load was expected to increase with respect to the conventional VAV system.

(2) Selection of cooling applications

In this study, chilled water plant for the conventional VAV system and cooling tower for the liquid desiccant system were designed on the basis of the peak cooling load. The capacity of these components was estimated according to the process given in section 4.4. The electric chiller capacity was 660 kW, and COP of the chiller was 4.45. In order to simulate the electric chiller and cooling tower performance, the manufacturer's data were used. The pump capacity of the chiller was 40 500 kg/h, the fan of the cooling tower was operated at 4.4 kW and the pump capacity of the cooling tower was 68 300 kg/h.

The solution cooling plant of the proposed system was composed of a cooling tower and pump for the cooling tower. The following manufacturer's data were used for CASE 1: five fans operating at 3.7 kW and a 273 m^3/h nominal water flow rate for the cooling tower. The following data were used for CASE2: three fans operating at 5.6 kW and a 188 m^3/h nominal water flow rate for the cooling water.

(3) Estimation of heating energy demand

The required area of the solar thermal collector for heating the solution was estimated by via simulation using RET screen. The demand solar thermal heating capacity was found to be 1645 kW in CASE 1 and 2300 kW in CASE 2. A high target heating setpoint for the solution necessitated a high heating capacity. The demand solar collector area could be estimated from this result. The demand solar collector area was 2352 m^2 in CASE 1 and 3300 m^2 in CASE 2.

(4) Comparison of operating energy consumptions

When the outdoor air was humid and the wet-bulb temperature of the outdoor air was higher, the thermal performance of the cooling tower decreased. Even in the worst-case scenario for the outdoor air, the solution could be cooled to at least 32 C, and the effectiveness of the liquid desiccant system was not significantly affected. The average temperature of the outlet desiccant solution was 30.26 C, and the standard deviation was 0.42 C.

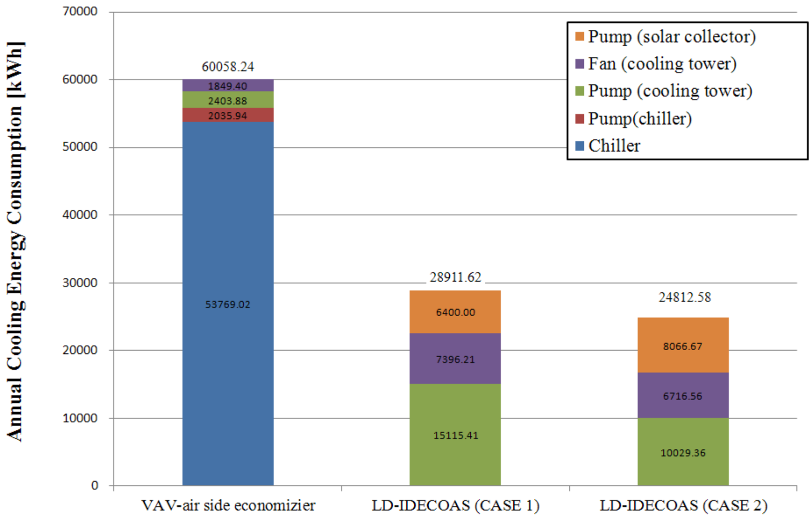

Figure 3. *Comparison of annual cooling energy consumptions for different systems and CASEs*

As shown in Figure 3, the VAV system had higher annual energy consumption than the proposed system. In CASE 1, the proposed system, which had a heating setpoint of 60 C, required about 48% of the operating energy of the VAV system. In CASE 2, where the heating setpoint was 45C, the proposed system required about 41% of the VAV system's operating energy. This means that 51.8-58.7% of the operating energy can be saved by using the proposed system as opposed to the conventional VAV system.

The lower energy consumption of the proposed system is principally due to the reduced usage of the conventional chiller than in the conventional VAV system. Solution cooling can be effectively achieved without the conventional chiller. The disadvantage of the initial design capacity resulting from a high peak solution cooling load is efficiently offset by the potential for saving operating energy. When a solar thermal collector is used as the solution heating source, more pump energy is consumed than in a conventional VAV system. However, this can be offset by reducing the chiller operating energy used in the conventional VAV system.

CONCLUSION

This study evaluated the applicability of a cooling tower to a liquid desiccant cooling source for a desiccant and evaporative cooling assisted 100% outdoor air system in Seoul, Korea which is classified as humid subtropical and humid continental climate. A solar thermal collector was assumed to be the solution heating source of the proposed system. Although the solution cooling load of the proposed system was 41-63% higher than the cooling coil load of the conventional VAV system, the proposed system had 52-59% less energy consumption than the conventional VAV system during the cooling season.

One may conclude that cooling tower can be effectively applied as a liquid desiccant solution cooling source and that it leads to significant energy saving potential for the cooling energy. The liquid desiccant and evaporative cooling system can be used as an alternative to conventional cooling coils.

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