Design Procedure for a Liquid Dessicant and Evaporative Cooling Assisted 100% Outdoor Air System

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ABSTRACT
When designing a desiccant and evaporative cooler based 100% outdoor air system, energy and thermal performance are significantly affected by three major components. These are the indirect evaporative cooler, direct evaporative cooler, and liquid desiccant system. In this proposed system, two types of systems can be obtained by applying a sensible heat exchanger in the OA intake. Because of these design elements of the proposed system, the design process is not easy to understand.
This paper thus presents a design process and a tool for the design of a liquid desiccant and evaporative cooler based 100% outdoor air system. Specifically, this paper shows a method for estimating the capacity of a liquid desiccant system depending on the system configurations. Seven design steps are required to determine the liquid desiccant system, and indirect and direct evaporative cooler capacities. How the design affects the indoor thermal environment is also evaluated. The proposed design procedure could provide a system solution to the HVAC system consultant and designer.

KEYWORDS
Design procedure, liquid desiccant system, evaporative cooling system, 100% outdoor air system

INTRODUCTION
The environmental problems of the conventional refrigerant based cooling system have been recognized as globalized environmental issues. Several harmful consequences of ozone layer depletion have caused the HVAC industry to phase out CFC and HCFC refrigerant in vapour compression systems. Thus, many researches have been investigated to provide suitable and energy efficient alternative indoor air conditioning systems (Kim et al. 2011, Jeong et al. 2003). A desiccant air condition system and evaporative cooling system is one of them. Many research works have been conducted in terms of a liquid desiccant system, in order to alter the conventional air conditioning system. Experimental researches have also been constantly carried out, beyond theoretical analysis (Gommed and Grossma 2007, Jain et al. 2011). Meanwhile, research on indirect and direct evaporative cooling based

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100% outdoor air system (IDECOAS), to control the indoor environment only by outdoor air, are also actively in progress (Kim et al. 2011a, Kim et al. 2011b).
The efforts to configure the energy saving potential of the HVAC system, however, have been to reduce the load and energy consumption of the conventional vapour compressor cooling coil, not to alternate cooling coil. To overcome this limitation, this research proposes a liquid desiccant in evaporative cooling assisted 100% outdoor air system. However, in order to conduct the research of feasibility in providing a HVAC system for buildings, much more experimental researches and applications are needed. For this point of view, the information given by researchers to engineers who want to apply the proposed system is necessary but rare.
The main objective of this study is to present a design process for the proposed system. The applicability of the proposed system is also examined, by conducting a pilot system design, and by estimating the latent cooling capacity of a liquid desiccant system. Simplified latent cooling capacity estimation model for the proposed system is also derived.

A LIQUID DESICCANT AND EVAPORATIVE COOLING BASED 100% OUTDOOR AIR SYSTEM

(1) System configuration

The system proposed in this research is composed of a liquid desiccant (LD), indirect evaporative cooler (IEC), and direct evaporative cooler (DEC) at the process air side. A heating coil and a sensible heat exchanger (SHE2) are located at the exhaust air side of the system. A double duct or a multizone system is applied, in order to handle different thermal environment demands in each room. The process air volume is adjusted, depending on load variation, like a VAV system. Depending on the selected configuration, an additional sensible heat exchanger (SHE1) can be applied upstream, prior to the LD.

(2) Operating scheme of the system

The proposed system is configured with the main characteristic concept of a decoupled system, which is a decoupling of the sensible and latent load of the outdoor air. During the cooling season, hot and humid outdoor air is primarily dehumidified, and the latent load is removed by LD. Then, sensible cooling is performed by IEC and sensible cooling and humidification are also performed by DEC in series. When it is difficult to maintain the target supply air temperature, caused by an extremely hot and humid climate, SHE1 can be located upstream, prior to the LD.
In intermediate season, when the outdoor air is dry enough to cool the process air by only IEC and DEC, the liquid desiccant is not operated. The process air passed through the IEC and DEC in series is divided into a cold deck and a neutral deck. The neutral deck supply air temperature setpoint is met by recovering waste heat from the exhaust air, via the SHE2.
In heating season, the sensible heat is recovered from the exhaust air through the SHE2 and IEC working as a sensible heat exchanger, in order to keep the neutral deck air temperature setpoint. On the other hand, when the SHE1 is located and heat recovered with exhaust air from the IEC secondary side, the heating demand to keep the target supply air temperature can be efficiently reduced.

DESIGNING AN LD-IDECOAS SYSTEM

In order to design the proposed system, seven main steps are suggested for efficient HVAC system design. Following these steps, a pilot system was designed for experimental investigation of the performance of the proposed system.

(1) Step 1. Determine the space peak cooling load

The space design cooling load should be estimated, prior to designing the proposed system. The energy performance of the building can be estimated by two overall approaches. Steady-state analysis is the simplest estimation method. This method is faster and easier than the other methods; however, it has less accuracy. Dynamic simulation can provide an accurate and detailed evaluation; but still, it is not easy to input data, and it takes a long time to calculate. The development of computer technologies leads to easy estimation of space cooling and heating load by using dynamic simulation software (e.g. Energyplus, TRNSYS, and ESP-r).

(2) Step 2. Determine target space conditions and supply air conditions

Proper target zone temperature and humidity should be selected for many reasons, for instance saving energy consumption, or political issues. ASHRAE Standard 55 suggests a thermal indoor recommendation range for comfort zone, depending on the various seasons. A genetic indoor thermal condition is 24℃ dry-bulb temperature, and 50% of relative humidity.

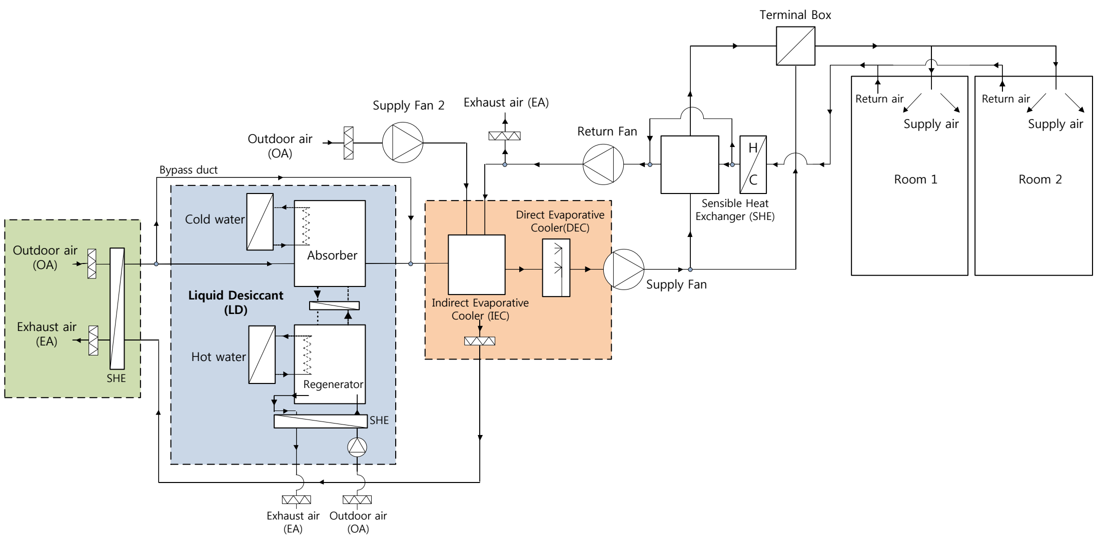
Latent space load and dehumidification have become critical issues in buildings. The high humidity level of indoor conditions could lead to discomfort to the occupants, as well as unhealthy indoor environments from the growing of biological contaminants. For handling the building latent load, the dew point temperature of supply air should be low to eliminate space latent load.

(3) Step 3. Determine design outdoor air conditions

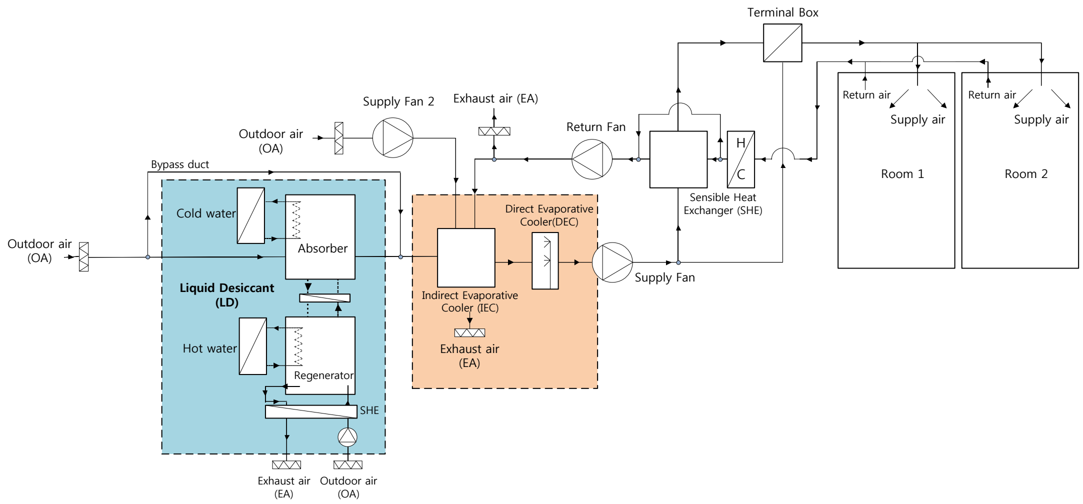
In order to design and size common HVAC systems, the climatic design conditions are used as annual percentiles of 0.4, 2, 5, and 10%. When 0.4 or 1% of the design condition is used, the HVAC system is over-sized and rarely operated under full-load. This part load operation may result in the reduction of system efficiency.

In order to avoid over-sizing the system, the design weather condition should be selected within the risky range of 2.5~5%, suggested by the ASHRAE TAC (Technical Advisory Committee). This method could provide the chance of reducing the capacity of the system and initial costs. And by reducing the part load ratio, poor system performance and low economic efficiency could be prevented.

(4) Step 4. Determine system configurations



(a) System configuration 1 – with SHE1



(b) *System configuration 2 – without SHE1*

***Figure 1** Two cases of system configurations*

In the proposed system, the supply air condition is maintained by passing the LD, IEC, and DEC in series. In the case of hot and humid weather conditions, however, the target supply air condition might not be satisfied by limitation of the effectiveness of the LD, IEC, and DEC. As shown in Figure 1, the proposed system could be divided and configured mainly in two types.

The dry-bulb temperature of the polluted return air is maintained between about 20 to 26℃, regardless of the effectiveness of the IEC. When this air is once more heat-exchanged with outdoor air in front of the LD, the sensible cooling load of the outdoor air can be efficiently pre-conditioned (Figure 1(b)).

(5) Step 5. Determine IEC, DEC, and SHE1 effectiveness

As reported in open literature, a range of effectiveness of the major components can be expected. The IEC effectiveness shows 30 to 80% (Kim et al. 2011b, Kruger et al. 2010), DEC shows 60 ~90 % (Wu et al. 2009), and SHE1 shows 40 ~ 70% (Wetter 1998), normally. In this system, supply air temperature is modified and changed by dehumidified rates of the LD and water supply rates of the IEC and DEC. In that, the cooling capacity of the IEC and DEC has an important role to control low-supply air temperature.

(6) Step 6. Determine supply air temperature and flow rates

Based on the selected system configuration and components effectiveness, determined in the previous step, the supply air temperature can be estimated. The supply air dry-bulb temperature could be modulated under the conditions of SHE1, IEC, and DEC effectiveness, and system configuration. On the other hand, the selected dew-point temperature or humidity ratio of the supply air should be maintained.

(7) Step 7. Determine liquid desiccant system and required dehumidification rate

The target outlet humidity ratio of LD can be estimated and the latent cooling capacity of LD is finally estimated with supply air flow rates. The LD is divided into two parts; dehumidification part and regeneration part. The process air is directly in contact with the concentrated desiccant solution, and the moisture of process air is then absorbed, due to the vapour difference between the desiccant solution and the air. With the identical reason, a diluted solution by absorbing the moisture is regenerated after heating.

In order to design the liquid desiccant system, the desiccant solution should be selected. TEG, LiBr, LiCl, CaCl2 have been widely used and investigated to configure the system. The most affected element to effectiveness of the LD is the liquid desiccant gas ratio (L/G ratio). And it also directly affects the components energy consumption.

SIMPLE MODELS FOR SYSTEM DESIGN

(1) Contribution of the effectiveness of the components

In this research, in order to recognize the influence of the effectiveness of the components to the required latent cooling capacity of the LD, quantitative, linearity and contribution analysis with maximum and minimum value of effectiveness is conducted. As shown in Table 1, the minimum and maximum effectiveness of IEC, DEC, and SHE1 was organized and used for analysis. TAC conditions were also considered.

Table 1. *Low and high level of each parameter*

Factor	*Name*	*Parameter*	*Unit*	*Minimum*	*Maximum*
A	Dry bulb temperature of outdoor air	T_{OA}	C	30	40
B	Relative humidity of outdoor air	RH_{OA}	%	50	80
C	Dry-bulb temperature of target space condition	T_{RA}	C	24	28
D	Effectiveness of IEC	ε_{IEC}	%	0	70
E	Effectiveness of DEC	ε_{DEC}	%	60	100
F	Effectiveness of SHE1, SHE2	ε_{SHE}	%	0	70
G	Peak cooling load per unit floor area	q_{PC}	W/m2	25	60

The results, as in Figure 2, show that system configuration 2 required more latent cooling capacity than that of system configuration 1. In the case of system configuration 1, SHE1 effectiveness variation does not much affect the required latent cooling capacity; on the other hand, system configuration 1 applied in the SHE1 needs less latent cooling capacity than that of system configuration 2. It can be also seen that LD latent cooling capacity might be significantly affected by SHE1.

Both system configuration 1 and 2, moreover, it is also shown that effectiveness of IEC and DEC is significant variable which affects the latent capacity of LD. The TAC conditions, in contrast, show that they are not significant variables in determining the LD capacity.

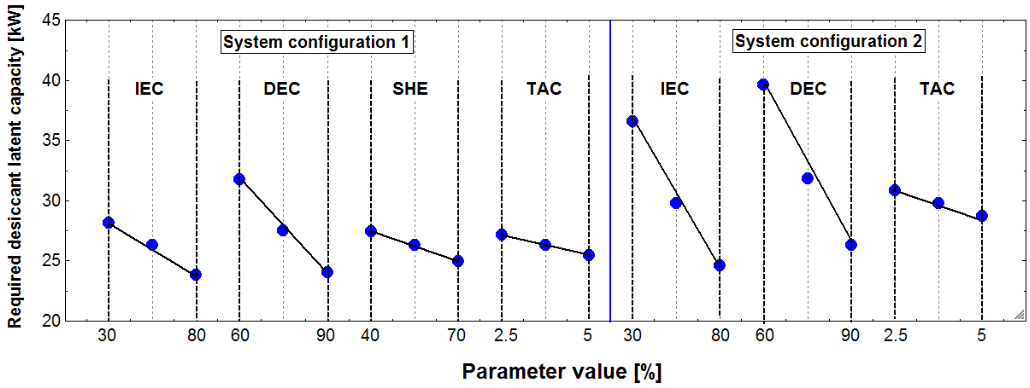


Figure 2. *The influence of the effectiveness of components on the required latent cooling capacity*

(2) Simplified model for design

In order to determine the required LD latent cooling capacity, complex equation calculation is needed. However, it is to be expected that the estimation of system design is difficult, in terms of this complexity in the initial design and investigation stage.

Therefore, a simple linearized model is derived for estimating the required latent cooling capacity ($q_{lat,LD}$), using selected seven variables as shown in Table 1. In this section, a simple correlation, which predicts the required latent capacity of LD, was derived by using 2k factorial experiment design.

Highly influenced design variations are found through the analysis methods of normal probability plot, half-normal probability plot, and Pareto chart. The results, shown in Table 2, provide the most influential seven single factors and two two-factor interactions, and the contribution of terms could also be estimated, given by the total sum of squares divided by each sum of squares. The results show that the range of selected terms contribution is from 44.07 to 0.34%, and variables that contribute lower than 0.3% are negligible.

Based on this result, a first order linear regression model, which obtains the required latent cooling capacity, was derived as a function of the above selected parameters and interactions. The R^2 value for the proposed model is 0.978. The required coefficients are presented in Table 3.

Table 2. *Selected parameters and percent contribution of the required latent cooling capacity model*

Factor	A	B	C	D	E	F	G	AB	AE
Parameter	T_{OA}	RH_{OA}	T_{RA}	ε_{IEC}	ε_{DEC}	ε_{SHE}	q_{PC}	$T_{OA} \cdot RH_{OA}$	$T_{OA} \cdot \varepsilon_{DEC}$
Contribution (%)	44.07	25.87	4.51	0.91	2.01	0.34	27.25	1.23	0.66

$$q_{lat,LD} = \alpha_0 + \alpha_1(T_{OA}) + \alpha_2(RH_{OA}) + \alpha_3(T_{RA}) + \alpha_4(\varepsilon_{IEC}) + \alpha_5(\varepsilon_{DEC}) + \alpha_6(\varepsilon_{SHE})$$
$$\alpha_7(q_{pc}) + \alpha_8(T_{OA} \cdot RH_{OA}) + \alpha_9(T_{OA} \cdot \varepsilon_{DEC}) \quad (1)$$

Table 3. *Coefficients for the required latent cooling capacity model*

α_0	α_1	α_2	α_3	α_4
-10.63875	0.24881	0.07194	-0.08907	-0.00333
α_5	α_6	α_7	α_8	α_9
0.01784	-0.00145	0.02504	-0.00124	-0.00069

CONCLUSION

This investigation formulated a design process for a desiccant and evaporative cooling based 100% outdoor air system. However, the design process of the proposed system has high complexity, and it leads to time-consuming work. To overcome this limitation, a correlation model using 2k factorial experimental method was also derived, which can be easily applied at the initial phase of desiccant latent cooling capacity design.

In the proposed system, SHE1 is necessary to save operating cost and reduce LD latent cooling capacity, while application of SHE1 could cause increase in the initial cost. The low effectiveness of IEC, DEC, and SHE1 leads to an increase of the supply air temperature and air flow rates. From this point of view, a high effectiveness of application can configure an energy efficient system, but it is not easy to follow, because of limitations of effectiveness, and initial costs in reality. Indeed, more extensive experimental research and field measurements are required.

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