2018

Removal Effect of Bio-contaminants in a Packaged Liquid Desiccant-assisted Air Conditioning Unit

Hye-Won Dong
Hanyang university, Korea, Republic of (South Korea), hwdong3@hanyang.ac.kr

Jae-Weon Jeong
Hanyang university, Korea, Republic of (South Korea), jjwarc@hanyang.ac.kr

Removal Effect of Bio-contaminants in a Packaged Liquid Desiccant-assisted Air Conditioning Unit

Hye-Won DONG[1], Jae-Weon JEONG [1]*

[1]Hanyang University, Department of Architectural Engineering,
Seoul, 04763, Republic of Korea
Contact Information (+8222202370, +82222201945, jjwarc@hanyang.ac.kr)

* Corresponding Author

ABSTRACT

The purpose of the study is to evaluate the removal effects of microbial contamination, such as fungi and bacteria, on a packaged liquid desiccant-assisted air conditioning unit. Recently, a package unit of a liquid desiccant and indirect and direct evaporative cooling-assisted 100% outdoor air system (LD-IDECOAS) was proposed. The LD-IDECOAS consists of a liquid desiccant system, an indirect evaporative cooler, and a direct evaporative cooler. The test was conducted under operating conditions during the cooling season when the LD-IDECOAS operates a liquid desiccant system, an indirect evaporative cooler, and a direct evaporative cooler. The sampling is performed ate the inlet (outdoor air) and outlet (supply air) of the package unit. Fungi were cultured in a potato dextrose agar (PDA) medium, and bacteria were cultured in a tryptic soy agar (TSA) medium as indices of bio-contaminants. The results indicated that the concentration of fungal contamination in the supply air (that passes through the package unit) decreased by 7.7% when compared to that of outdoor air. The concentration of bacterial contamination in the outlet was also reduced by 72.4% when compared to that in the inlet. Hence, the package unit improves air quality by removing bio-contaminants, such as fungi and bacteria, although unexpected contamination occurred in the experiment.

1. INTRODUCTION

Recently, liquid desiccant systems and evaporative cooling technologies are proposed as alternatives to vapor compression cooling systems that cause global warming and ozone depletion (Goetzler *et al*., 2014). The liquid desiccant system is located at the upstream side of an evaporative cooler, designed to dehumidify air. Thus, it enhances the cooling performance of the indirect evaporative cooler such that the performance of the air conditioning system improves when the two systems are collectively operated. Kim *et al*. (2013; 2014; 2015) developed an outdoor air-conditioning system based on dehumidification evaporative cooling that combines two non-vapor compression technologies while using 100% outside air called as LD-IDECOAS. Ham *et al*. (2016) proposed a liquid desiccant and dew point evaporative cooling-assisted 100% outdoor air system called as LDEOS by using a liquid desiccant and a dew point evaporator. Gao *et al*. (2015) proposed a system that combines a liquid dehumidifier and a Maisotesenko-cycle indirect evaporative cooler. Several extant studies examined an air conditioning system that combined a liquid desiccant system and an evaporative cooling system for many years. However, most of them focus on the energy saving aspect of the air conditioning system. Thus, there is a lack of research on indoor air quality improvement.

The desiccant solution of liquid desiccant system has sterilization effect whereas the water vapor of process air is condensed during the dehumidification process using conventional cooling coil, and this process increases microbial contamination such as bacteria and fungi (Rafique *et al*., 2016). Chung *et al*. (1995) evaluated removal rate of indoor air pollutants in the liquid desiccant system using a triethylene glycol solution. They measured the concentration of toluene and formaldehyde at the inlet and outlet of liquid desiccant system. The result showed that the outlet concentration of pollutants decreased when compared to the inlet because of adsorption effect of the solution. Zhang *et al*. (2004) analyzed the removal effect of volatile organic compounds (*i.e.*, formaldehyde) in the

liquid desiccant using lithium bromide solution as a desiccant solution, and the concentration of formaldehyde decreased at the outlet of liquid desiccant system. Wang et al. (2011) compared the removal effect of microbial contamination between lithium chloride and triethylene glycol solution in the liquid desiccant system. As a result, the removal rate of contamination with triethylene glycol solution was higher than that with lithium chloride solution.

There are two types of evaporative cooler: direct and indirect. Because a process air and water directly meets in a direct evaporative cooler (DEC), it has a potential of microbial contamination. This contamination can cause respiratory disease such as *Legionella*'s disease. *Legionella* bacteria rarely multiply in the DEC operating range (*i.e.*, 20–24℃ air and water). However, there is a potential to detect *Legionella* bacteria as well as other microbial contaminants because, when a DEC operates inside the air conditioning system, a DEC pad is exposed to various temperature range (Gómez *et al.*, 2010).

Previous studies confirmed that the liquid desiccant system displays a microorganism removal effect and confirmed that microorganisms, such as Legionella, are likely to proliferate in direct air and water contact systems such as a direct evaporative cooler or a cooling tower. Therefore, the purpose of this study is to evaluate the removal effect of microbial contamination in the packaged LD-IDECOAS unit.

2. PACKAGED LIQUID DESICCANT-ASSISTED AIR CONDITIONING UNIT

The LD-IDECOAS is mainly composed of a liquid desiccant (LD) system, an indirect evaporative cooler (IEC), and a direct evaporative cooler (DEC) as shown in Figure 1. Previous studies (Kim *et al.*, 2013; 2014; 2015) indicated that LD-IDECOAS can save primary energy when compared to a conventional variable air volume system. The proposed system is an environmentally friendly air conditioning system that also reduces greenhouse gas emissions by using non-vapor compression technologies. However, the proposed system exhibits a complex configuration, and it is difficult to control three main devices because the devices operate in various ways based on the outdoor air condition or season. In addition, each device of LD-IDECOAS is too large in terms of applying it to an actual air conditioning system. A package unit of LD-IDECOAS was constructed to solve the above-mentioned problems, and thus air paths and pipelines are simplified while minimizing the heat loss and improving controllability.

The LD system in the package unit includes an adiabatic cross flow configuration in which the desiccant solution is sprayed from upside and flows down due to gravity while the process air is blown in a cross-flow direction relative to the solution flow. The primary air channel and the secondary air channel in the IEC constitute the cross flow and water flow in the secondary channel. The DEC also corresponds to the cross-flow type, and this is identical to the LD system. The packings of the LD and DEC correspond to CELdek® 7060-15. The design flow rate of package unit is 500 m^3/h, and liquid to gas ratio of the LD system is set as 1. The return air is used as the secondary air of IEC.

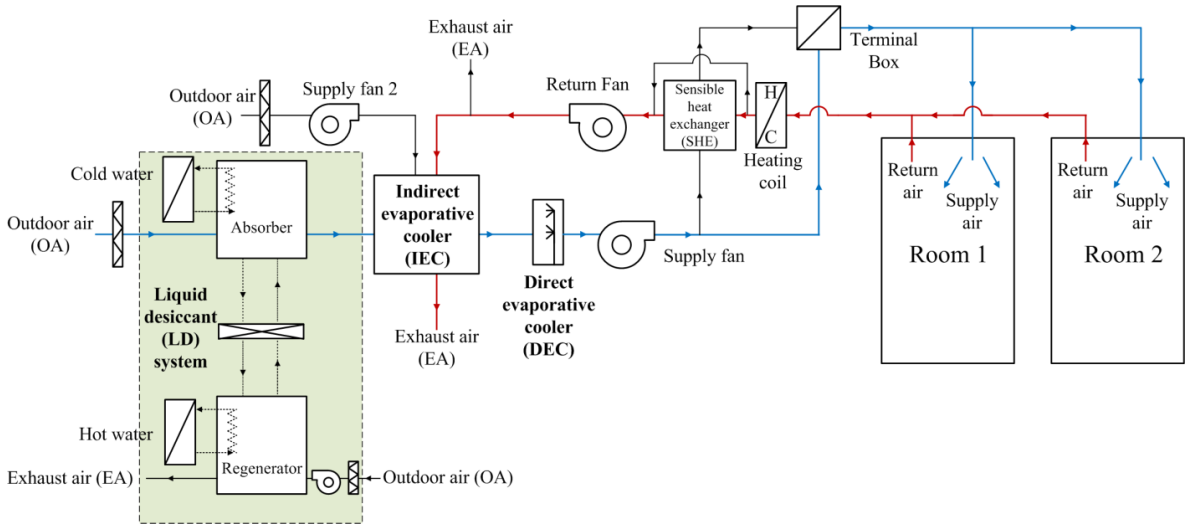


Figure 1: Concept of LD-IDECOAS

As shown in Figure 2, the operation mode of the proposed system is divided into four different regions (i.e., Region A to D) based on outdoor air (OA) conditions (Kim *et al.*, 2015). Region A represents hot and humid OA conditions, and the LD, the IEC, and the DEC are activated to satisfy the supply air (SA) set condition (*i.e.*, 15℃). Region B indicates that OA is hot and dry, and thus the IEC and DEC are activated without the LD operation to satisfy the SA set point. In Region C, only DEC operates to satisfy the SA dry bulb temperature set point because the enthalpy of OA is lower than that of SA. Finally, the LD and DEC are deactivated, and the IEC is used as the sensible heat exchanger (SHE) when the dry bulb temperature of OA is lower than that of SA (Region D).

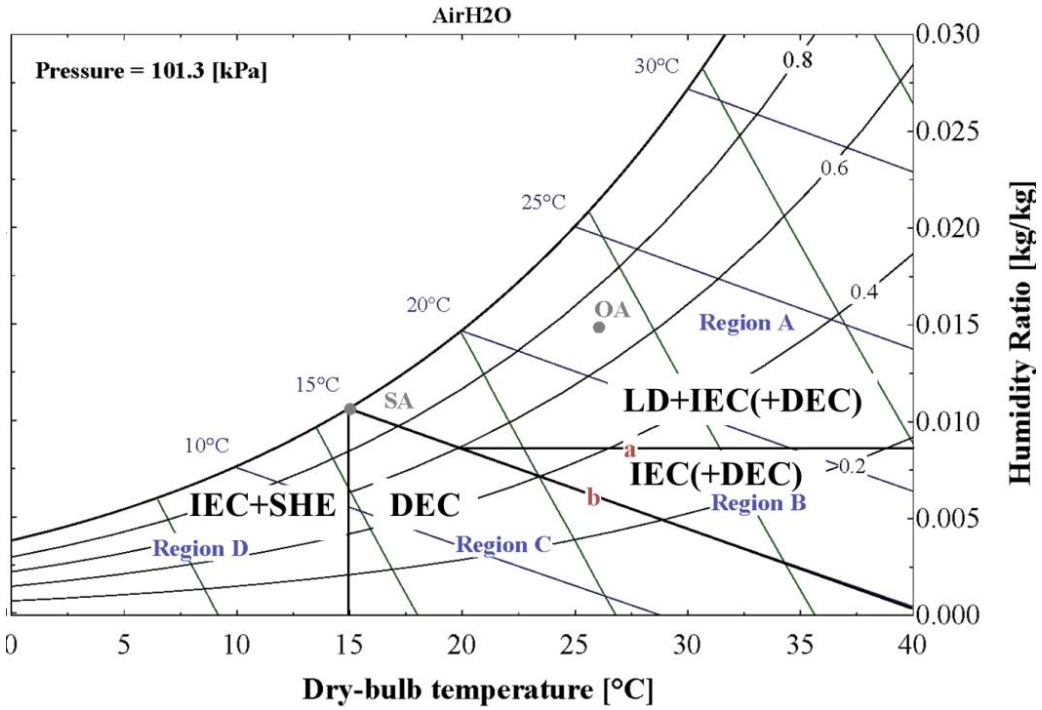


Figure 2: Operation mode of LD-IDECOAS on a psychrometric chart

3. EXPERIMENTAL SETUP

3.1 Test conditions

The packaged LD-IDECOAS unit was installed in a building located in industrial area in Incheon, Republic of Korea, and handles a single zone load. Experiments were conducted under the outdoor air conditions corresponding to Region A (Figure 2) where all devices (*i.e.*, LD, IEC, and DEC) of the LD-IDECOAS operated. The supply air flow rate was 500 m^3/h, and this corresponds to the design supply air flow rate of the proposed package unit. A lithium chloride aqueous solution was used as a desiccant solution, and the concentration of solution supplied in the absorber was approximately 36%. Circulating water was used for the water sprayed on the secondary channel for the IEC, and running water was supplied for the DEC. A filter was not installed in the package unit. The measurements started 30 minutes after turning on the package unit. The ranges of outdoor and supply air conditions during the experiment are shown in Table 1.

3.2 Sampling method

In order to confirm the biological contaminants removal effect of packaged LD-IDECOAS unit, microorganisms were collected at the inlet and outlet of package unit (*i.e.*, the outdoor air and the supply air side). Figure 3 shows the cross section of package unit and sampling positions. The outdoor air was sampled in the chamber prior to passing it through the liquid desiccant system in the package unit, and the supply air was sampled in the distributor of the air conditioning zone.

Table 1: Outdoor and supply air conditions

Bio contamination	Location	Conditions	Ranges
Fungi	OA	Temperature	23–25℃
		Relative humidity	50–60%
	SA	Temperature	20℃
		Relative humidity	60%
Bacteria	OA	Temperature	25–27℃
		Relative humidity	50–60%
	SA	Temperature	25℃
		Relative humidity	50%

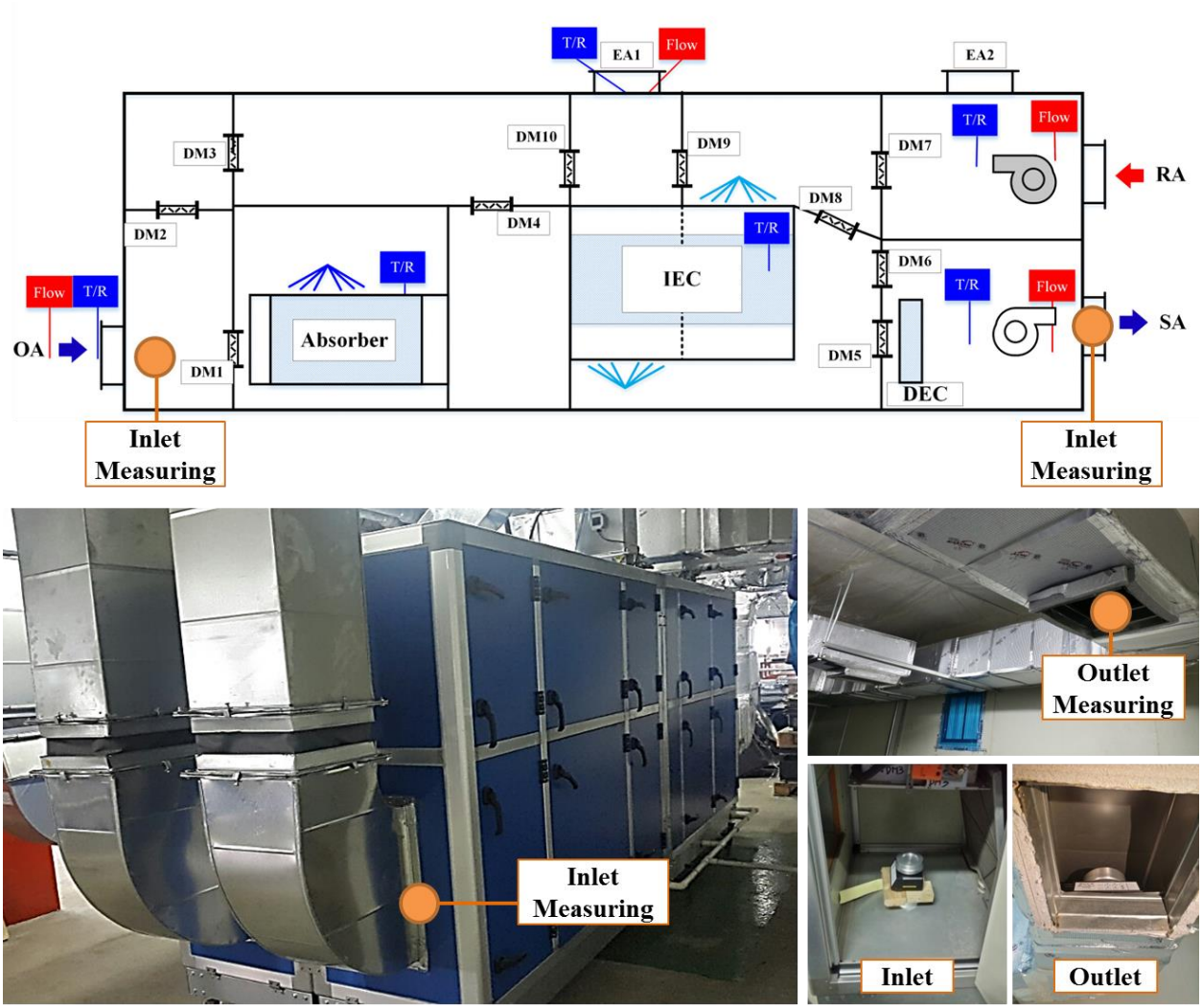


Figure 3: Sampling position

An impactor air sampler (*i.e.*, BUCK BioCulture Model B30120) was used to collect microorganisms. Table 2 shows the details of the used air sampler. Potato dextrose agar (PDA) and Tryptic soy agar (TSA) were used to quantitatively estimate biological contaminants removal effect of package unit. PDA and TSA were used to detect fungi and bacteria, respectively. Air at each position was sampled with a PDA and TSA in a 90 mm plate based on the air sampler compatibility.

The number of sampling based on bio-contaminants is shown in Table 3. Based on ISO 16000-17 (2011) and ISO 16000-18 (2011), at least four agar plates with two different sampling volumes that were analyzed in parallel are available per medium in order to ensure the validity of the experimental results. In this study, the date of experiment differed based on the type of medium, and two sets were conducted with a time difference during a single day. Regardless of the type of medium, samples were taken twice at each sampling volume (*i.e.*, 100 L, 200 L, and 500 L). The air sampler samples corresponded to 100 L/min, and thus it was equivalent to 5 min for 500 L. Hence, 28 PDA and TSA plates were used.

Table 2: Specification of the bio-contaminants sampler (BUCK BioCulture Model B30120)

Device	**Type**	**Characteristics**	
Bio-contaminants sampler	Impactor type	Detection flow	30–120 L/min
		Compatibility	90 mm agar plate
		Holes	380 (1 mm diameter)
		Accuracy	± 5% of the set point

Table 3: Number of sampling

Bio-contaminants	**Operation period**	**Number of samplings**	**Number of samples by sampling volume**
Fungi (PDA)	1 day	2 times	100 L: 2 times
			200 L: 2 times
Bacteria (TSA)			500 L: 2 times

Before starting the experiment, sterilization around the sampling area, air sampler, and latex gloves was performed with 70% alcohol for each measurement to prevent contamination and maintain the same experimental conditions. The agar plate was opened for 5 seconds without using an air sampler, which represents the base case, prior to sampling the bio-contaminants by using the air sampler to check the contamination around the sampling site. After sampling, the plate was sealed with a parafilm to prevent further contamination while moving. It is necessary to store the collected samples at 25℃ or lower to prevent deformation of the sample until it is placed in the incubator. Therefore, they were kept in the cooler while moving from the sampling area to the incubator. Table 4 shows the incubate conditions of each bio-contaminant.

Table 4: Sampling and incubate conditions

Bio-contaminants	Sample material	Sampling method	Agar type	Incubate temperature	Incubate times
Fungi	Air	Impactor air sampler	PDA	25℃	5 Days (120 h)
Bacteria	Air	Impactor air sampler	TSA	32℃	3 Days (72 h)

4. EXPERIMENTAL RESULT

After counting the number of microbial populations by each bio-contaminant, the microbial concentration (CFU/m^3) collected by the impactor type air sampler was calculated by using Equation (1) based on ISO 16000-17 (2008). The concentration (C) is the ratio of total number of colony forming units on the agar plates ($\sum N_{cfu}$) to the total sampling volume ($\sum V$). The base case was performed before starting each set, and the number of microbial populations was zero in all base cases. In this study, the first set of each bio-contaminant is representatively shown as follows:

$$C = \frac{\sum N_{cfu}}{\sum V} \quad (1)$$

4.1 Fungi

Tables 5 shows the first sampling set of fungal contamination levels in the outdoor and supply air. In the first set, it was confirmed that the number of fungal colonies in the supply air decreased when compared to that in the outdoor air. In the second set, it is difficult to clearly count colonies because the yellow spore-shaped fungus spread throughout the PDA medium. However, the number of fungal colonies decreased or showed a trend similar to that of the first set while counting only the fungi forming colony. Bacteria and enzymes were suspected at times although they were excluded during counting.

4.2 Bacteria

Table 6 shows the first set of bacterial contamination levels in the outdoor and supply air. In contrast fungi, bacterial counts of the first set were visually confirmed, and the number of bacterial populations in the supply air significantly decreased when compared with that in the outdoor air. The number of bacterial colonies in the second set also decreased as shown in the first set. Microorganisms that are presumed as fungi and enzymes were also observed in the TSA medium although the experiment only involved counting the bacteria colonies and did not include fungi and enzymes.

Table 5: Number of fungi colonies in the first set

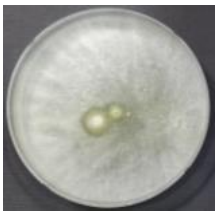
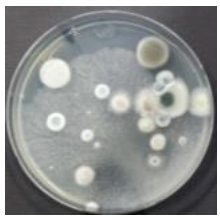
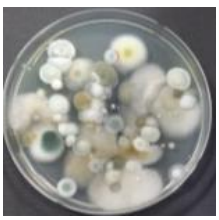
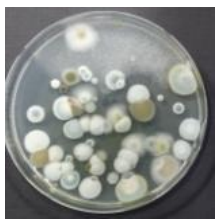
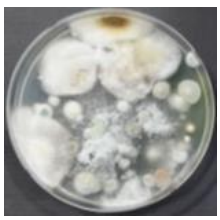
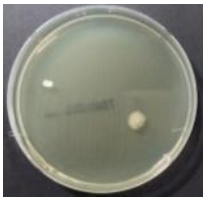
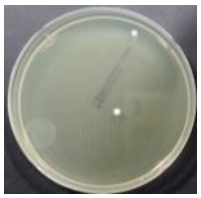
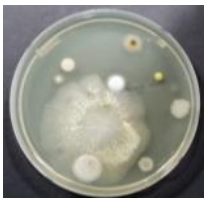
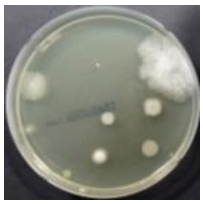
Measuring time	**1st sample**		**2nd sample**	
Measurement number	OA	SA	OA	SA
Base				
Number of colonies [CFU]	0	0		
Number of colonies [CFU]				
200 L	7	11	12	11
500 L				
Number of colonies [CFU]	28	23	31	16
5 min				
Number of colonies [CFU]	50	54	49	48
C [CFU/m^3]	OA		SA	
	110.6		101.9	

Table 6: Number of bacteria colonies in the first set

Measuring time	**1st sample**		**2nd sample**	
Measurement number	OA	SA	OA	SA
base				
Number of colonies [CFU]	0	0		
100 L				
Number of colonies [CFU]	5	5	7	3
200 L				
Number of colonies [CFU]	18	3	15	6
500 L				
Number of colonies [CFU]	16	10	36	10
C [CFU/m^3]	OA		SA	
	60.6		23.1	

5. DISCUSSION

In the present study, the removal efficiency of fungi in a packaged LD-IDECOAS unit was calculated as 8.0% and 7.4% in the first set and the second set, respectively. In the first and second sets of bacteria, the removal efficiency was 61.9% and 82.8%, respectively. The indirect evaporative cooler is expected to be free from water contamination even if circulating water is used in the indirect evaporative cooler because the primary channel and secondary channel are completely separated. In addition, the removal effect by the filter is absent since the package unit of the

proposed system is currently built without a filter. Therefore, the improvement in the supply air quality is potentially because the removal efficiency of the microorganisms in the liquid desiccant system exceeds that of the direct evaporative cooler.

The number of fungal colonies appeared to exceed that of bacterial colonies in the running water sprayed on the air in the direct evaporative cooler or the process air. Although a time difference existed on the same day when sampling the fungi, the experiment was performed under similar outdoor conditions. However, the spread of fungi spores was suspected in all the second set. This is potentially because the surrounding disinfection was not thoroughly performed or the environment changed due to unexpected circumstances. The position sampling of the supply air is located in the distributor of the air conditioning zone and not in the chamber of package unit as in the case of outdoor air sampling position, and thus there is a possibility of contamination by the duct inside. However, it is determined that the contamination inside the duct is removed because the experiment was performed 30 min later since the air conditioning system was turned on. Consequently, the package unit improves air quality by removing the bio-contaminants, such as fungi and bacteria, although unexpected contamination occurred in the experiment.

6. CONCLUSIONS

In this study, the removal effects of microbial contamination, such as fungi and bacteria, on the packaged LD-IDECOAS unit were tested and analyzed. The experiment was conducted under the operating conditions during the cooling season when the LD-IDECOAS operates a liquid desiccant system, an indirect evaporative cooler, and a direct evaporative cooler. Fungi were cultured in a PDA medium, and bacteria were cultured in a TSA medium. The results indicated that the concentration of fungal contamination in the supply air (that passes through the package unit) decreased by 7.7% when compared to that of outdoor air. The concentration of bacterial contamination was also eliminated by an average of 72.4%. Additionally, the removal efficiency indicates that the package type dehumidification evaporative cooling based outdoor air conditioning system has a greater effect on bacteria compared to that on fungi. Measurement on the outlet side of each device is also necessary to accurately understand the influence of each device on the outdoor air conditioning system based on the packaged dehumidification evaporation cooling system. It is also expected that the removal efficiency is further increased by installing filters or ultraviolet lamps. It is expected that the air quality improvement effect is further improved in the remaining operating conditions in which the direct evaporative cooler is not necessary since the experiment was performed with a direct evaporative evaporator cooler, which is known to exhibit the most significant influence on air pollution.

NOMENCLATURE

C	microbial concentration	(CFU/m^3)
N	number	(CFU)
V	sampling volume	(m^3)

Subscript

cfu	colony forming units

REFERENCES

BUCK BioCulture. Bio-contaminants sampler Model B30120 Technical brief.

Chung, T. W., Ghosh, T. K., Hines, A. L., & Novosel, D. (1995). Dehumidification of moist air with simultaneous removal of selected indoor pollutants by triethylene glycol solutions in a packed-bed absorber. *Separation Science and Technology*, 30(7-9), 1807–1832.

Evaporative Cooling Pad, CELdek ® 7090-15. https://www.munters.com/

Gao, W. Z., Cheng, Y. P., Jiang, A. G., & Liu, T., and Anderson, K. (2015). Experimental investigation on integrated liquid desiccant–Indirect evaporative air cooling system utilizing the Maisotesenko–Cycle. *Applied Thermal Engineering*, 88, 288–296.

Goetzler, W., Zogg, R., Young, J., & Johnson, C. (2014). Energy savings potential and RD & D opportunities for non-vapor-compression HVAC technologies. Report prepared by Navigant Consulting, Inc. for the U.S Department of Energy.

Gómez, E. V., Martínez, F. R., & González, A. T. (2010). The phenomenon of evaporative cooling from a humid surface as an alternative method for air-conditioning. *Energy and Environment*, 1(1), 69–96.
Ham, S. W., Lee, S. J., & Jeong, J. W. (2016). Operating energy savings in a liquid desiccant and dew point evaporative cooling-assisted 100% outdoor air system. *Energy and Buildings*, 116, 535–552.
ISO16000-17. (2011). *Indoor Air–Part 17: Detection and Enumeration of Moulds–Culture-Based Method.* Geneva, Switzerland: International Organization for Standardization (ISO).
ISO16000-18. (2011). *Indoor Air–Part 18: Detection and Enumeration of Moulds–Sampling by Impaction*. Geneva, Switzerland: International Organization for Standardization (ISO).
Kim, M. H., Park, J. S., & Jeong, J. W. (2013). Energy saving potential of liquid desiccant in evaporative cooling-assisted 100% outdoor air system. *Energy*, 59, 726–736.
Kim, M. H., Park, J. Y., Sung, M. K., Choi, A. S., & Jeong, J. W. (2014). Annual operating energy savings of liquid desiccant and evaporative-cooling-assisted 100% outdoor air system. *Energy and Buildings*, 76, 538–550.
Kim, M.H., Park, J.Y., & Jeong, J.W. (2015). Simplified model for packed-bed tower regenerator in a liquid desiccant system. *Applied Thermal Engineering*, 89, 717–726.
Rafique, M. M., Gandhidasan, P., & Bahaidarah, H. M. (2016). Liquid desiccant materials and dehumidifiers–A review. *Renewable and Sustainable Energy Reviews*, 56, 179–195.
Wang, Y. F., Chung, T. W., & Jian, W. M. (2011). Airborne fungi inactivation using an absorption dehumidification system. *Indoor and Built Environment*, 20(3), 333–339.
Zhang, W. R., Qu, K. Y., Liu, X. H., & Chang, X. M. (2004). Pilot study of the impact of liquid desiccant dehumidification on IAQ. *Journal of HV&AC*, 11, 114–117.

ACKNOWLEDGEMENT

This work was supported by the Korea Agency for Infrastructure Technology Advancement (KAIA) grant (17CTAP-C116268-02), and the Korea Institute of Energy Technology Evaluation and Planning (KETEP) (No. 20164010200860).