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Hygienic investigation of the evaporative cooling system installed in air handling units

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Abstract. A significant portion of the total summer energy consumption of buildings is allocated to the treatment of ventilation air and cooling of spaces. One possible approach to reduce mechanical cooling energy consumption is indirect evaporative cooling. By implementing this method, the mechanical cooling energy demand of air handling units can be significantly reduced. Numerous studies and literature focus on the energy analysis of direct and indirect evaporative cooling system solutions. However, the hygiene assessment of these processes has received less attention thus far. This article presents an examination of the hygiene of evaporative cooling panels and the water used in these systems. The aim of the study is to assess the level of hygiene risk and explore potential cleaning technologies. It was shown that the applied disinfection method in this cooling system, using chemical solution flushing (in the case of 3 w/w% hydrogen peroxide solution) has proven more effective than chemical surface spraying process.

1. Introduction

A significant portion of the summer energy consumption of buildings is devoted to meeting cooling and ventilation demands [1]. In larger industrial and commercial buildings, these demands are met using an air handling system. The central component of the air handling system is the air handling unit. To reduce the cooling energy consumption of air handling units, heat recovery system solutions have been developed [2]. One possible method for further reducing the cooling performance requirements of air handling units is the application of direct and indirect evaporative cooling [3]. In this process, water is evaporated into the treated air without the input of external thermal energy. During the nearly adiabatic state change, the air cools and its moisture content increases [4]. In dry, hot climates, direct evaporative air cooling is more widespread [5]. In this case, the air treated by evaporative cooling is delivered directly to the occupied zone. During indirect evaporative air cooling, the exhaust air and the air exiting to the outside are subjected to evaporative cooling. This increases the temperature difference between the treated exhaust air and the fresh air from outside, thereby enhancing the cooling performance obtained through the heat recovery unit integrated into the air handling unit, compared to traditional methods [3]. The application of evaporative air cooling results in significant energy savings; however, it also introduces hygiene risks. During the process, the air comes into direct contact with water, which can serve as a breeding ground for bacteria and other microorganisms [6]. Using the measurement station established in the Air-Ventilation and Air-Conditioning Laboratory, University of Debrecen, Department of Building Services and Building Engineering, several long- and short-term studies were conducted. These studies demonstrate that under the continental climatic conditions characteristic of Central Europe, the application of indirect evaporative cooling provides significant energy advantages, warranting further research to develop its widespread and safe application. The measurement station in the laboratory allows us to investigate the extent of microbiological risk under given conditions. The focus of the study is to preliminarily test commonly used disinfection methods to guide future research directions.

2. Materials and Methods

In Air-Ventilation and Air-Conditioning Laboratory, a unique measurement station was established. The test bench is similar in technical design to the typical direct evaporative air coolers available on the market. The examined air cooler is equipped with a cellulose-based cooling medium. Water is circulated between the water tank and the water distributor device with the help of a pump. This technical design was investigated because it is one of the most hygienically risky arrangement. The air continuously contacts the water in the water tank, allowing the water to capture organic contaminants introduced by the air. The water in the tank is refreshed slowly, as the mass flow rate of the evaporated water is low, which may allow microorganisms to proliferate in the water tank. The technical design of the evaporative air cooling unit under study is common and one of the earliest configurations on the market. [7]. Investigations of similar units have shown that their use without maintenance and cleaning poses significant hygiene risks [8].

2.1 Evaporative cooling unit

The water tank of the evaporative air cooling unit is made of stainless steel. A float valve is responsible for maintaining the water level. Water is pumped from the tank to the water distribution unit. The water flows through the cooling pad, creating a large exposed water surface, which provides optimal conditions for evaporation.

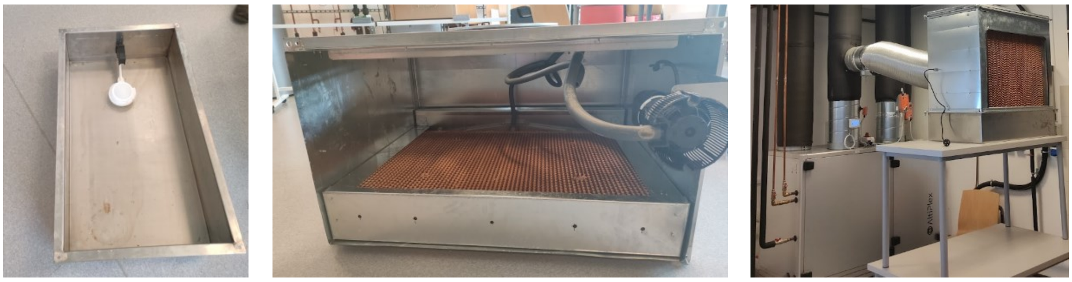

Figure 1. Evaporative cooling unit

The evaporative air cooling unit shown in Figure 1 was developed in 2020. Since then, the evaporative unit has been continuously measured and tested during the cooling season, with minor interruptions. The use of the evaporative air cooling unit over such an extended period allows for an accurate representation of the hygienic condition of a unit operating under real conditions.

2.2 Measuring plan

The hygiene tests were conducted between January and June, 2024. The evaporative air cooler was connected to the laboratory's air handling unit. The evaporative air cooler treated air extracted from the interior (air volume flow rate: 1000 m^3/h) and was operated as an indirect evaporative cooler. The evaporative air cooler was supplied with untreated potable water from the municipal water network.

During the measurements, the salt concentration and conductivity of the tank water were examined. During our test the water analytical parameters (temperature, conductivity, salinity) of the tank water where also measured by suitable electrodes of a Multiline P4 meter (WTW GmbH, Weilheim, Germany, Figure 2).

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Figure 2. Multiline P4 meter

HygieneChek™ PLUS microbiological rapid tests (Romer Labs Inc, USA) were applied for hygiene tests to determine the potential presence of E. coli colonies (ECC) and number of coliform bacteria after 24 h incubation period, furthermore coliform bacteria and total germ count (TTC) after 48/72 h incubation period, in semi-quantitative method. The incubation temperature during both tests was 35 °C, which is provided in Peltier-cooled incubator (Memmert, Germany). The tests consist of a plastic container with a screw-off cap and a double-sided plastic pad, which enables the simultaneous examination of microbes on two culture media/nutrient soil. The tests are suitable for analysis from air, surface or liquid (Figure 3). The great advantage of rapid tests is that they are fast, some tests can be read after 24 hours, they are also easy to use, and no microbiology lab is required for their application. The obtained results were given in units of colony-forming unit (CFU)/mL.

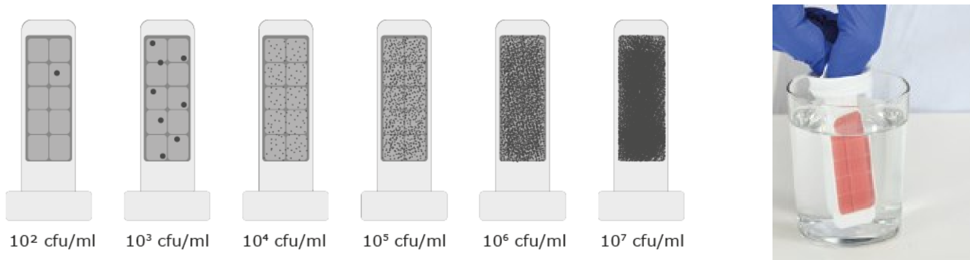


Figure 3. a, Sample paddles to estimate the values of colonies; b, Water sampling illustration

The applied disinfection agent was the 3 w/w% hydrogen peroxide solution (Scharlab, Spain). The hygiene requirements of air handling systems and the indoor air quality requirements are based on the VDI 6022 standard [9]. In order for the water used in the air handling system to be recyclable, the limit values listed in Table 1 must be met. The measurements were not conducted according to the VDI 6022 standard; therefore, the results approximate the expected outcomes of the tests prescribed by the standard.

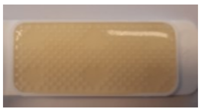
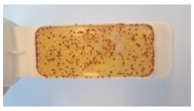
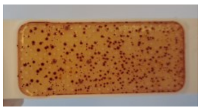
Table 1. Needed hygiene parameters for "recirculating water" based on VDI 6022 standard

Procedure/hygiene parameter	Assessment values for recirculating water
Total CFUs (bacteria) as per DIN EN ISO6222	< 1000 CFU/mL
Legionella sp. as per DIN EN ISO 11731	< 100 CFU/mL
Pseudomonans aeruginosa as per DIN EN ISO 16266	< 100 CFU/mL

3. Results and discussion

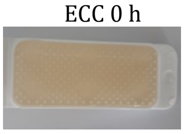
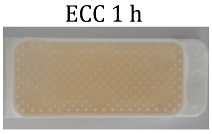
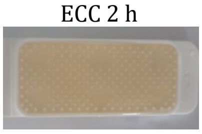
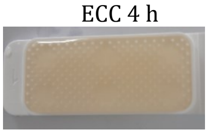
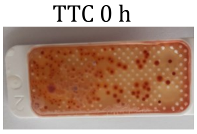
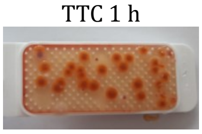
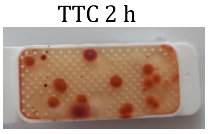
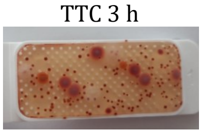
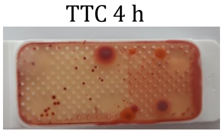
The evaporative cooler unit underwent testing in three conditions. Prior to the first series of measurements, the tank of the evaporative cooler underwent solely mechanical cleaning. As shown in Table 2, mechanical cleaning did not provide adequate protection against microbiological contaminants. Based on the measurement series, it can be stated that no presence of E. coli colonies or coliform bacteria was observed. However, in terms of coliform bacteria count and TTC, the estimated CFU values did not meet the requirements of the VDI 6022 standard (after 48/72h incubation). Due to continuous evaporation of water from the tank, the dry matter content in the tank increased, thereby increasing the conductivity. The initial conductivity value of 621 μScm^{-1} increased to 896 μScm^{-1} during the 4-hour operation.

Table 2. The evaporative cooling box with only mechanical cleaning

Measurements 15.04.2024; 9:15-13:15				
ECC 0 h	ECC 1 h	ECC 2 h	ECC 3 h	ECC 4 h
				
$<10^2$ CFU/mL	$<10^2$ CFU/mL	$<10^2$ CFU/mL	$<10^2$ CFU/mL	$<10^2$ CFU/mL
TTC 0 h	TTC 1 h	TTC 2 h	TTC 3 h	TTC 4 h
				
10^4-10^5 CFU/mL	10^4-10^5 CFU/mL	10^4-10^5 CFU/mL	10^4-10^5 CFU/mL	10^4-10^5 CFU/mL
Measured physical properties of water				
621 μScm^{-1}	729 μScm^{-1}	797 μScm^{-1}	840 μScm^{-1}	896 μScm^{-1}
22.5 °C	17.5 °C	17.3 °C	17.3 °C	17.2 °C

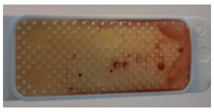
The above measurement was repeated three times with mechanical cleaning. The measurements yielded similar results. Upon reviewing the results, an alternative cleaning method was tested. Prior to commencing the measurement series, the evaporative panel surface was sprayed with a 3 w/w% hydrogen peroxide solution. The water tank was filled after the spraying. The results after spraying are summarized in Table 3. According to the measurement, initially the TTC showed similar trends, followed by a decrease in estimated colony count. During the measurement period, the evaporative cooler unit did not meet the requirements of the VDI 6022 standard. Over the course of the measurement, the water conductivity increased from 629 μScm^{-1} to 863 μScm^{-1}.

Table 3. The surface of cooling media sprayed with hydrogen peroxide solution (concentration: 3%)

Measurements 29.04.2024; 9:00-13:00				
ECC 0 h	ECC 1 h	ECC 2 h	ECC 3 h	ECC 4 h
				
$<10^2$ CFU/mL	$<10^2$ CFU/mL	$<10^2$ CFU/mL	$<10^2$ CFU/mL	$<10^2$ CFU/mL
TTC 0 h	TTC 1 h	TTC 2 h	TTC 3 h	TTC 4 h
				
10^4-10^5 CFU/mL	10^4-10^5 CFU/mL	10^3-10^4 CFU/mL	10^3-10^4 CFU/mL	10^3-10^4 CFU/mL
Measured physical properties of water				
629 μScm^{-1}	716 μScm^{-1}	757 μScm^{-1}	803 μScm^{-1}	863 μScm^{-1}
19.5 °C	16.5 °C	16.2 °C	16.0 °C	15.8 °C

Based on the obtained results, microbial contamination was suspected in the pump and piping system of the evaporative cooler. To disinfect the equipment, the tank was filled with a 3 w/w% hydrogen peroxide solution. Subsequently, the pump of the equipment was operated to circulate the solution for 5 minutes. After the procedure, the solution was drained, and the tank was refilled with potable water. The results of the measurement conducted after the procedure are summarized in Table 4.

Table 4. The cooling box full pre cleaning with hydrogen peroxide (concentration: 3%)

Measurements 6.05.2024; 10:10-14:10				
ECC 0 h	ECC 1 h	ECC 2 h	ECC 3 h	ECC 4 h
				
<10^2 CFU/mL	<10^2 CFU/mL	<10^2 CFU/mL	<10^2 CFU/mL	<10^2 CFU/mL
TTC 0 h	TTC 1 h	TTC 2 h	TTC 3 h	TTC 4h
				
10^3 CFU/mL	<10^2 CFU/mL	<10^2 CFU/mL	10^3 CFU/mL	<10^2 CFU/mL
Measured physical properties of water				
620 μScm^{-1}	629 μScm^{-1}	655 μScm^{-1}	693 μScm^{-1}	733 μScm^{-1}
21.6 °C	18.2 °C	18.0 °C	18.0 °C	18.2 °C

Based on the results, it can be stated that no presence of E. coli colonies or coliform bacteria was observed. In terms of coliform bacteria count and TTC, the estimated CFU (colony-forming unit) count already met the requirements of the VDI 6022 standard. During the measurement, the conductivity changed to a lesser extent. This is because the measurement was conducted on a rainy day, resulting in less evaporated water compared to previous measurements, thus leading to a minor increase in salt concentration.

4. Conclusion

The aim of the measurement series is to identify research directions that can more thoroughly uncover the hygiene risks associated with evaporative cooling and explore possible methods of managing them. Conclusions drawn from the measurements include:

- Even during prolonged dry periods, significant concentrations of viable microbiological contaminants can remain in evaporative coolers.
- Based on the measurement results, periodic disinfection of evaporative coolers is necessary to meet the requirements of VDI 6022.
- According to measurement experiences, chemical solution flushing has proven more effective than chemical surface spraying (in the case of 3 w/w% hydrogen peroxide solution).

In the future, our goal is to test alternative disinfection methods. Additionally, we aim to investigate the extent of degradation caused by disinfection procedures in the evaporative cooler equipment, as well as the impact of this degradation on the humidification efficiency of the evaporative panel.

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