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# Environmental and hygienic assessment of direct evaporative air-cooling systems

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**Abstract.** This research focuses on the application of direct evaporative air cooling from the perspective of environmental engineering, with a particular emphasis on hygienic and microbiological safety. Evaporative cooling is a sustainable, energy-efficient technology increasingly used in industrial halls, workspaces, and facilities that require high air exchange rates. While the method is advantageous in terms of energy use and simplicity, its effectiveness is limited by the increase in air humidity, which may be unsuitable in certain comfort spaces. Therefore, the primary aim of this research is to assess the hygienic implications of direct evaporative cooling, with special attention to the potential presence of microbiological contaminants such as *Escherichia coli* (*E. coli*) and other harmful bacteria in the treated air and cooling water. Key research objectives include identifying the environmental and operational conditions under which microbial contamination may develop and determining how these risks can be effectively monitored and minimized. To achieve this, a set of microbiological and environmental analytical techniques were applied. Sampling procedures utilized specialized microbiological air samplers and water collection methods. Air and water samples were analyzed to determine the number of *E. coli*, total germ count (TTC), and various analytical parameters such as pH, electrical conductivity, salinity, total dissolved solids (TDS), turbidity, total organic carbon (TOC). The results were evaluated based on the relevant health and safety standards to quantify the hygienic risks posed by evaporative cooling systems and to propose mitigation strategies. This research contributes to the understanding of evaporative cooling technology from a public health and environmental engineering perspective.

## 1. Introduction

The evaporative cooling process is an energy-efficient cooling method in which water is evaporated into the air without the input of external heat energy. The energy required for the phase change is supplied from the internal energy of the system. During the process, the temperature of the system (air-water mixture) decreases. If the goal of the process is to cool water as a heat transfer medium, evaporative cooling towers are often used [1]. If the goal is to cool air, evaporative air coolers are applied [2]. During evaporative air cooling, the air temperature decreases while its humidity increases. Evaporative air cooling is commonly used for

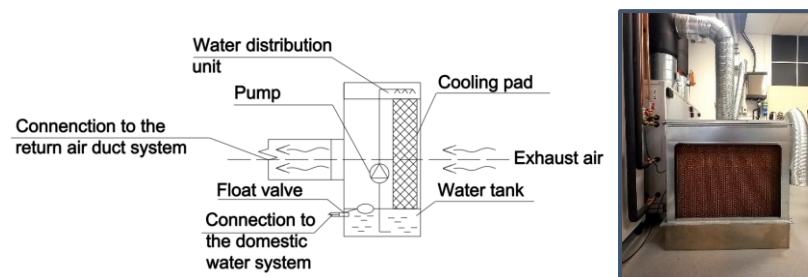


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technological cooling and the treatment of comfort spaces. In the case of direct evaporative air-cooling devices, the cooled air is delivered directly to the occupied zone. In such cases, particular attention must be paid to hygiene issues related to the process. Based on investigations conducted in 2024 at the Air Technology Laboratory of the University of Debrecen, it became evident that microorganisms may be able to proliferate in direct evaporative air-cooling units [3]. The aim of the present study is to examine the hygienic risks associated with the use of evaporative air-cooling units by testing a potential disinfection solution. The study also includes a preliminary investigation into the degradation of the humidification panel inside the evaporative air cooler. The relevant microbiological and general water analytical measurements were implemented in the Water Quality Protection Laboratory, Faculty of Engineering.

## 2. Materials and Methods

The evaporative air-cooling unit was connected to the air handling system of the Air Technology Laboratory. Measurements of the unit were conducted between March and May 2025. The structure of the unit is illustrated in Figure 1. In the tested setup, the water tank is in direct contact with the extracted air. From the tank, water is pumped into the distribution unit. Within the distribution unit, the water is evenly distributed and then flows through the evaporative panel. The evaporative panel is a cellulose-based filter that, by moistening the surface with flowing water, creates a large free water surface. Along this large free surface, water can efficiently evaporate into the airstream passing through. Excess water flows back into the tank. The evaporated water is replenished from the drinking water supply through a float valve.



**Figure 1.** Evaporative cooling unit

The advantage of the tested arrangement is that it is simple in construction and water-saving, as excess water flowing through the humidification panel is returned to the tank. However, contaminants from the air can enter the water tank with the water, thereby creating a proper culture medium for microorganisms. The evaporative air cooler was tested by running several test cycles. Water samples were taken every hour during the 4-hour test operation. The microbiological contamination of the water samples was examined with rapid hygiene tests (HygieneCheck PLUS, Romer Labs Inc., USA). The presence of E.coli colonies (E.C.C.; 24 h incubation period at 35 °C) and total germ count (48 h and 72 h incubation period at 35 °C) can be detected with these tests using a Memert incubator. During the analytical measurements (Figure 2) various parameters such as pH, electrical conductivity, salinity, total dissolved solids (T.D.S.) values were measured with a Multiline P4 meter (WTW GmbH, Weilheim, Germany); turbidity was tested with a Turb 555IR light scattering photometer (WTW GmbH, Weilheim, Germany) and Total Organic Carbon (T.O.C.) values were also measured with a Shimadzu TOC-Vcpn device (Shimadzu Europe GmbH, Duisburg, Germany). Before the first measurement cycle of the air cooler, only mechanical cleaning was performed. The measurement series was repeated

three times under the same conditions, after mechanical cleaning and they were yielded similar results. Based on the results, an alternative cleaning method was tested. The disinfection of the equipment was carried out by filling the tank with a 3% hydrogen peroxide solution, then starting the pump of the equipment and circulating the solution for 10 minutes. After the procedure, the solution was drained and the tank was filled with drinking water.



**Figure 2.** a) HygieneCheck PLUS test; b) Multiline P4 meter (temperature, conductivity, salinity, T.D.S.) c) Shimadzu TOC-Vcph device (T.O.C.), d) Turb 555IR light scattering photometer (Turbidity)

Among the regulations concerning the quality of recirculated water in air handling systems, we considered the VDI 6022 standard [4]. The limit values are presented in Table 1. When presenting the measured results (Tables 2 and 3), values below the limit are marked in green, values close to the limit are marked in yellow, and values exceeding the limit are marked in red.

**Table 1.** Needed hygiene parameters for “recirculating water” based on VDI 6022 standard [4]











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 measured values during the operation of the evaporative air cooler are summarized in Tables 2 and 3. Based on the results, it can be established that the samples did not show the presence of E.coli colonies (E.C.C.) during the 4-hour operation of the evaporative air cooler system. Based on the total germ count (T.T.C.) tests, it was shown that the number of colonies after the 2-hour operation of the system exceeded the limits of the VDI6022 standard. During the measurement cycle, the pH and conductivity value of the water in the water tank of the system moderately increased. A possible reason for this is the increase in the specific dry matter concentration of the water due to evaporation. The amount of organic impurities in the water sample can also be characterized by testing the values of the Total Organic Carbon (T.O.C.), the value of which continuously increased during the measurement. This tendency in the organic matter concentration may result from the possible dissolution of the system's evaporator panel, which is made of natural organic material.








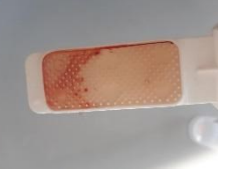
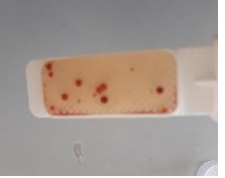

Before the measurement series summarized in Table 3, the evaporative air cooler system was disinfected with a 3% hydrogen peroxide aqueous solution. During the second measurement cycle, a significant decrease was observed in the measured values of the T.T.C. colonies and the Total Organic Carbon (T.O.C.) values. Based on these results it was shown that the water sample quality came closer to the expectations of the VDI6022 standard. It is important to note that the measurement procedures we use a slightly differ from the measurement practice prescribed by the referred standard.

**Table 2.** Hygiene test and analytical parameter results for the evaporative cooling system after only mechanical cleaning

E.C.C. 0h	E.C.C. 1h	E.C.C. 2h	E.C.C. 3h	E.C.C. 4h
				
<10 <sup>2</sup> CFU/mL	<10 <sup>2</sup> CFU/mL	<10 <sup>2</sup> CFU/mL	<10 <sup>2</sup> CFU/mL	<10 <sup>2</sup> CFU/mL
T.T.C. 0h	T.T.C. 1h	T.T.C. 2h	T.T.C. 3h	T.T.C. 4h
				
10 <sup>2</sup> CFU/mL	10 <sup>3</sup> CFU/mL	10 <sup>4</sup> CFU/mL	10 <sup>5</sup> CFU/mL	10 <sup>5</sup> -10 <sup>6</sup> CFU/mL
Measured analytical parameters of water				
Water temperature [°C]				
23.3	18.8	18.3	18.5	18.5
Water pH level				
7.13	7.48	7.85	7.99	7.99
Conductivity [ $\mu\text{S}\cdot\text{cm}^{-1}$ ]				
587	649	671	690	712
Turbidity [NTU]				
0.46	0.50	0.54	0.54	0.56
Total Organic Carbon values [ $\text{mg}\cdot\text{L}^{-1}$ ]				
7.07	30.01	33.80	36.94	38.14

When examining the measured data, a significant difference was observed in the water turbidity values. During the measurement cycle after chemical cleaning, the water turbidity exceeded the values experienced in the first measurement cycle. According to our hypothesis, the chemical cleaning process may cause material leaching.

**Table 3.** Hygiene test and analytical parameter results for the evaporative cooling system after full pre cleaning with hydrogen peroxide solution (concentration: 3%)

E.C.C 0h	E.C.C 1h	E.C.C 2h	E.C.C 3h	E.C.C 4h
				
<10 <sup>2</sup> CFU/mL	<10 <sup>2</sup> CFU/mL	<10 <sup>2</sup> CFU/mL	<10 <sup>2</sup> CFU/mL	<10 <sup>2</sup> CFU/mL
T.T.C 0h	T.T.C 1h	T.T.C 2h	T.T.C 3h	T.T.C 4h
				
10 <sup>3</sup> -10 <sup>4</sup> CFU/mL	10 <sup>3</sup> -10 <sup>4</sup> CFU/mL	<10 <sup>3</sup> CFU/mL	10 <sup>3</sup> CFU/mL	<10 <sup>2</sup> CFU/mL
Measured analytical parameters of water				
Water temperature [°C]				
24.5	16.1	16.6	14.8	15.5
Water pH level				
6.70	7.14	7.26	7.34	7.65
Conductivity [ $\mu\text{S}\cdot\text{cm}^{-1}$ ]				
497	517	533	544	565
Turbidity [NTU]				
0.52	0.55	0.57	0.69	0.70
Total Organic Carbon values [ $\text{mg}\cdot\text{L}^{-1}$ ]				
4.25	9.54	11.17	13.73	9.50

#### 4. Conclusion

Based on the measurements, it can be said that the use of evaporative air coolers in air conditioning systems may pose a hygiene risk that needs to be addressed. Generally, hygiene risks are not examined for such systems. Based on the measurement experiences, the following conclusions can be drawn:

- Mechanical cleaning of evaporative air coolers is insufficient – under the testing conditions.
- The chemical cleaning process used during the test (applying 3% hydrogen peroxide solution) can significantly reduce the total number of germs, so it was an effective disinfection solution for this system.
- The turbidity and T.O.C. values of the water in the system water tank increased significantly by using the chemical cleaning process. According to our hypothesis, due to the degradation of the evaporator panel caused these changes by chemical cleaning.

Based on the measurements, it can be seen that flushing with hydrogen peroxide solution is a promising method from a hygienic point of view, which can be a simple and economical way of hygienic regeneration of evaporative air-cooling equipment, however, it can reduce the service life of the evaporator panels. Fortunately, this panel is not an expensive part of the system, so it is advisable to replace it from time to time, while the tested disinfection solution effectively helps reduce microbiological risks.

In the future, our goal is to perform a long-term measurement series which supports the long-term effect test of the cleaning procedure on the physical parameters of the evaporator panel, primarily on the humidification efficiency, can be examined.

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