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THE EFFECT OF ULTRASONIC DIFFUSER ON INDOOR AIR QUALITY

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Abstract. *The usage of ultrasonic diffusers in indoors has raised concerns regarding their potential health effects, mostly due to the lack of research on the matter. This study's aim was to analyse the effect of distilled water, tap water, and tap water with essential oils droplets from an ultrasonic diffuser on the number of particle matter and microbiological contamination in indoor air under laboratory conditions during summer and winter seasons. The most common species throughout all experiments were the Gram+ Aerococcus viridans and Micrococcus luteus, accounting for 21.33% (93 CFU/m^3) and 13.76% (60 CFU/m ^{3}) of the total bacteria count. Four different fungal species were identified over both seasons, moulds were more common making up 81.25% (65 CFU/m ^{3}). It was noted that the microorganisms identified were not pathogenic, presenting no significant infection risk from the diffuser's use. Experiments involving the use of an ultrasonic diffuser with DW demonstrated that PM1, PM2.5, and PM10 levels can be maintained within acceptable ranges over a 4-hour period. However, these experiments also highlighted an increase in nanoparticle concentrations, for which current guidelines lack specific recommendations. The diffuser was cleaned before every experimental setup stage, avoiding any residual contamination.*

Keywords: *indoor air pollution, indoor air quality, microbial contamination, PM, ultrasonic diffuser.*

Introduction

The widespread deployment of ultrasonic diffusers in residential settings for air humidification and aroma dissemination has raised concerns regarding their potential health effects, particularly due to the lack of comprehensive research on the matter.

Using ultrasonic vibrations, these devices atomize water mixed with additives, such as essential oils, creating a fine mist that is subsequently dispersed into the surrounding air. In this study the use of various water types in an ultrasonic diffuser (distilled water (DW), tap water (TW), and water with

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added lavender essential oil (WALO)) was evaluated to investigate the influence of water composition on the generation of particulate matter (PM) by these devices. This is crucial to estimate the potential health effects posed by inhaling the resultant aerosols. Consequently, our investigation explores the assessment of microbiological alterations in air composition under laboratory conditions. This study's aim was to analyse the effect of distilled water, tap water, and tap water with essential oils droplets from an ultrasonic diffuser on the number of particle matter and microbiological contamination in indoor air under laboratory conditions during summer and winter seasons.

Literature review

Studies in epidemiology show a link between exposure to PM pollution and negative effects on respiratory and cardiovascular health. This includes reduced lung capacity, asthma, heart attacks, and an increase in deaths from all causes (Chen & Zhao, 2011). Indoor and outdoor pollutants differ significantly. Moreover, the origins of many air pollutants specific to indoor settings are still not well understood (Lau, Loebel Roson, Klimchuk, Gautam, Zhao, & Zhao, 2021).

Ultrasonic diffusers, widely utilized to enhance moisture levels in indoor environments, release different size particles <0,2-4 μm which quickly turn into vapor in indoor environments. It is believed (Yao, Dal Porto, Gallagher, & Dietrich, 2020) that approximately 90% of the emitted particles were in the inhalable 0.25–0.5 μm and <0.25 μm size. These particles are composed of inorganic chemicals, metals, organic compounds, fibres, and microorganisms that originate from the water used to fill the devices. The concentration of these dissolved components in the aerosolized output is directly proportional to their concentrations in the source water (Dietrich, Yao, & Gallagher, 2022).

It was discovered (Tyndall, Lehman, Bowman, Milton, & Barbaree, 1995) that reservoirs in all kinds of humidifiers were colonized by both clinically insignificant and overtly or potentially pathogenic microorganisms. However, it was primarily the cool mist and ultrasonic diffusers that efficiently aerosolized bacteria and endotoxins. Similar studies have also highlighted that ultrasonic diffusers can release significant quantities of respirable endotoxins quickly. Researchers (Lee, Ahn, & Yu, 2012) deployed an ultrasonic diffuser for 10 hours a day across a 15-day span within a residential setting. Initial observations showed no significant changes in bacterial concentrations, as assessed by tryptic soy agar (TSA) for the first three days. However, a substantial rise in bacterial levels began on the sixth day, with counts reaching 6979 CFU/m^3 and peaking at 46431 CFU/m^3 on the ninth day. Fungal proliferation saw a marked increase starting on the twelfth day, with concentrations ranging between 14424 and 16038 CFU/m$^{3\cdot}$ Interestingly, the presence of fungal growth initially led to a reduction in airborne bacterial concentrations, but once the fungal growth was eliminated, bacterial levels surged. This pattern suggests a competitive interaction for nutrients and space between the bacteria and fungi, influenced by the conditions created by the humidifier's use. Microbial proliferation within diffuser reservoirs may occur in the absence of routine decontamination between usage cycles.

It was observed (Yang, Chen, Yang, Gu, Cao, & Zhong, 2022) that microbial growth rates in diffuser reservoirs were highest in cold boiled water, followed by distilled water, whereas tap water exhibited the lowest rate of microbial proliferation. The authors discuss that the diminished microbial growth observed in tap water can be attributed to the substantial presence of free chlorine residuals, a byproduct of the water treatment processes, which serve to inhibit microbial proliferation. Conversely, cold boiled water is characterized by a high concentration of Chemical Oxygen Demand (COD) and Total Nitrogen (TN), compounds that likely provide essential nutrients for microbial growth. This differentiation in microbial growth dynamics across water types underscores the impact of water treatment residuals and nutrient availability on microbial ecosystems within humidifier reservoirs.

Methodology

This study was carried out in a space designed for the assessment of different pollutants in a laboratory setting. The volume of the experimental room was approximately 24.96 m^3. The ultrasonic diffuser was placed at a height of 1.15 m, all other measurement instruments were located on the same table near the ultrasonic diffuser. ELPI was in a room adjacent to the experimental room, through a designated hole in the wall specifically for this purpose. Ventilation of the room occurred before each experimental phase. Access to the room for the purpose of collecting experimental data was limited to only one person at a time and was done only when necessary. The diffuser used in this study was the Ultrasonic USB Colourful humidifier (model DQ-106) with a 0.3-liter capacity, it was sourced from a manufacturer in China, and can emit a mist volume of 30-45 mL/h. This device was operational for 4-hour intervals per session during both summer and winter seasons. Experimental trials were conducted over two consecutive days in three distinct phases, with control measurements recorded before to each phase. The study utilized three variations of water: distilled water, tap water directly from the laboratory's faucet, and tap water with added lavender essential oil (5 drops).

ELPI was used for the assessment of PM characteristics (0.006-1 μm), including number concentration, size distribution, and mass concentration. Additionally, PCE-RCM 16 was used for the evaluation of PM concentrations (PM1, PM2.5, PM10).

Microbiological sampling was conducted using a SAS Super ISO 100 air sampler. Bacterial cultures were cultivated on Trypticase Soy Agar (TSA) and incubated for 24 hours at 37°C, and fungi were cultivated on Sabouraud Dextrose Agar (SDA) and incubated for 48 hours at 22°C. The grown colonies were counted manually in terms of Colony Forming Units per cubic meter (CFU/m^3) and afterwards identified. Fungi were identified with native smears and safranin staining, whereas bacterial identification utilized Vitek2.

The ultrasonic diffuser was cleaned before every experimental setup stage to avoid any residual contamination.

Research results

Microbiology

Cumulatively over both seasons, a total of 22 bacteria species were identified, with one species remaining unidentified. Without the microbiological background there were 19 bacteria species. Out of these 19 species 68,42% (13) were Gram-positive (Gram+) and 26,32% (5) were Gram-negative (Gram-) bacteria (Figure 1). The distribution of identified species is shown in Figure 2.

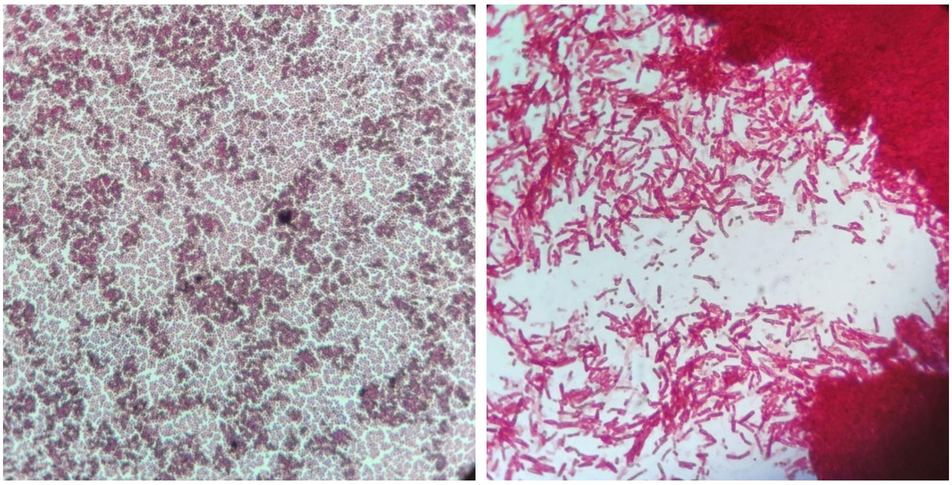

Figure 1 ***Gram-positive cocci and Gram-negative bacilli under microscope***

The most common species throughout all experiments were the Gram+ *Aerococcus viridans* and *Micrococcus luteus*, accounting for 21,33% (93 CFU/m^3) and 13,76% (60 CFU/m^3) of the total, respectively, and Gram- *Pseudomonas fluorescens*, accounting for 18,35% (80 CFU/m^3) of the total.

Regarding fungi, four different fungal species were identified over both seasons. Among these, moulds were more common, with Mucor spp. making up 42,50% (34 CFU/m^3), Aspergillus spp. 23,75% (19 CFU/m^3), and Penicillium spp. 15,00% (12 CFU/m^3). Additionally, a single yeast species, Candida spp., was identified, accounting for 18,75% (15 CFU/m^3) of fungi. See Figure 3 and Figure 4 for look under microscope.

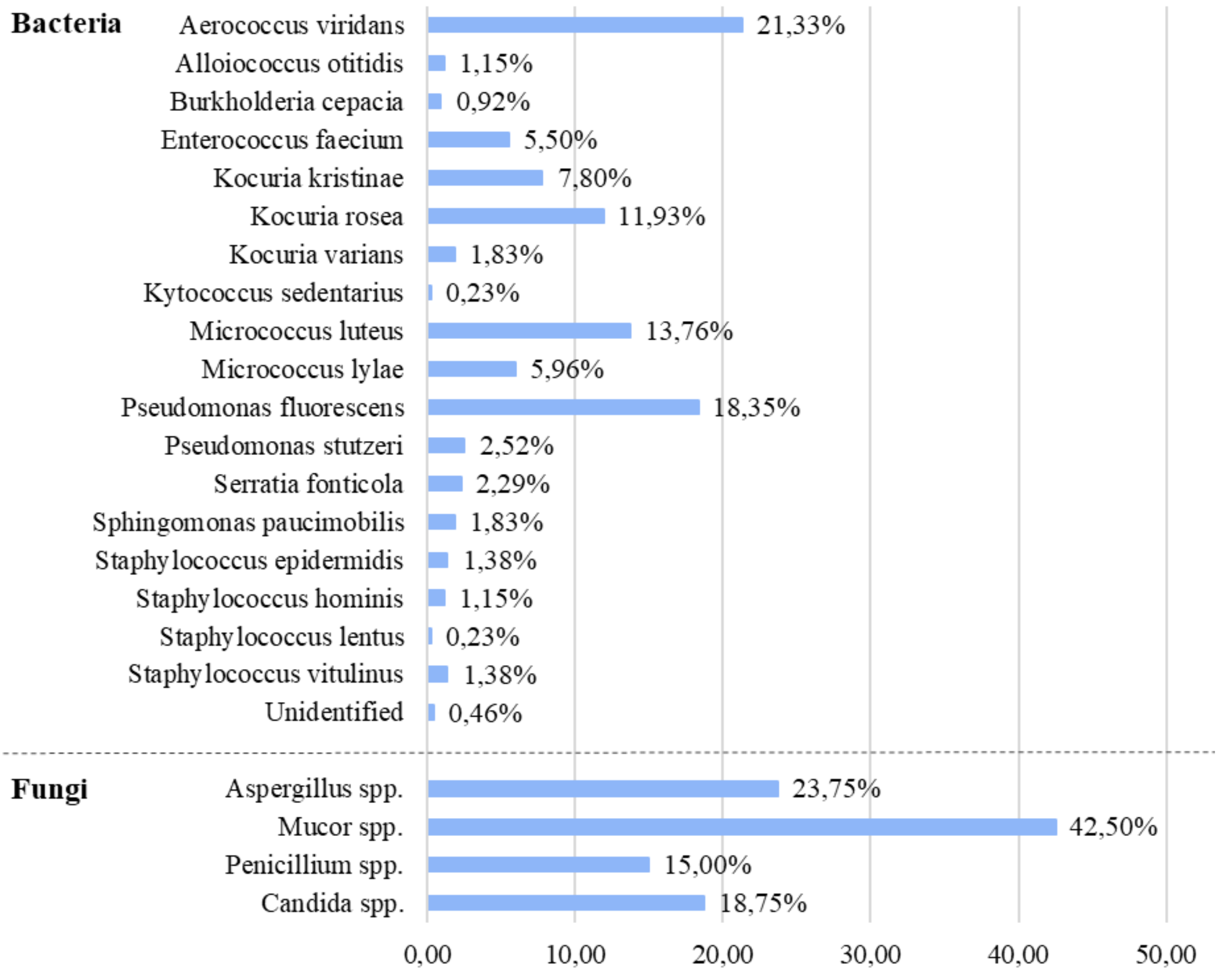

Figure 2 ***Identified species distribution by percentage***

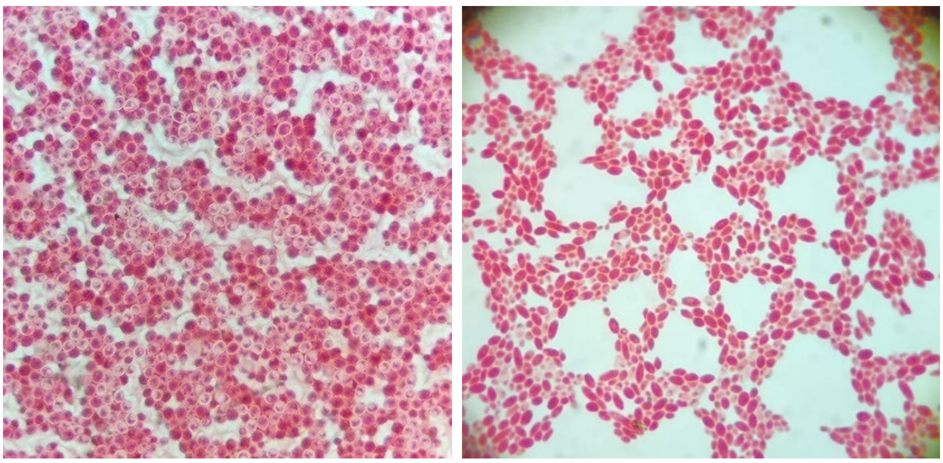

Figure 3 ***Candida spp. stained with safranin under microscope***

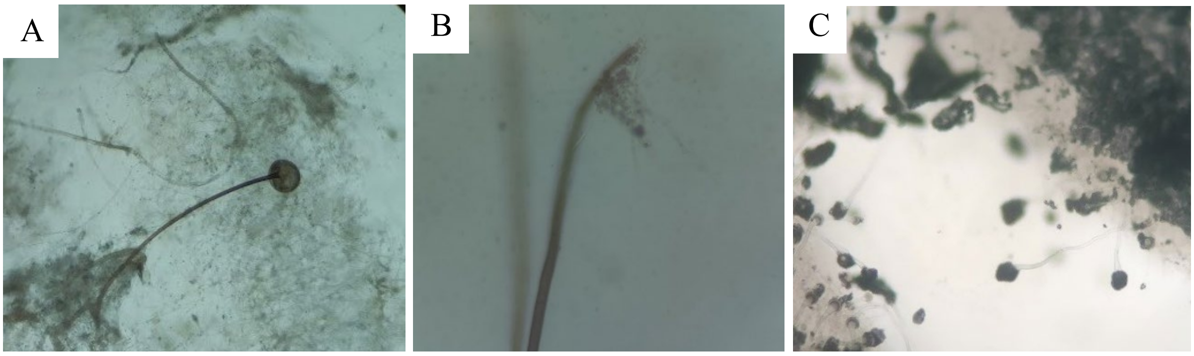

Figure 4 ***Native smears under microscope***
A. Mucor spp. B. Penicillium spp. C. Aspergillus spp.

It was noted that the microorganisms identified were not pathogenic, presenting no significant infection risk from the diffuser's use. The data indicated a general decrease in bacterial CFU/m^3 following diffuser use, with longer operation correlating with fewer bacteria, though not linearly. Seasonal variations were observed; summer setup showed a 100% increase in CFU/m^3, which did not align with winter results, suggesting potential data reliability issues. Fungi counts did not exhibit clear patterns, although it seems that the use of the ultrasonic diffuser decreases the CFU counts of fungi. All patterns can be seen in Figure 5. The overall data was insufficient to establish definitive correlations between diffuser operation duration and CFU/m^3 changes in fungi. Additional research is necessary for conclusive findings.

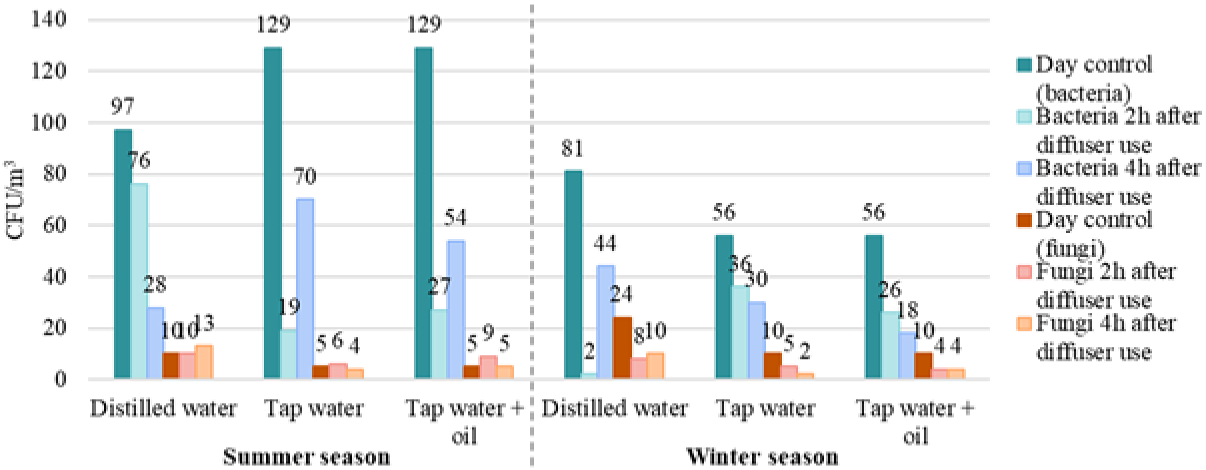

Figure 5 ***Microbial contamination during ultrasonic diffuser use***

Particles

In Figure 6, we can see the number concentration of particles by size. DW exhibits a very high number of small particles, particularly around 0.006 µm after 4 h work of ultrasonic diffuser, whereas TW presents a larger distribution across various particle sizes. For PM smaller than 1 µm, DW shows a lower total number concentration, amounting to $42*10^3$ particles/cm³. In contrast, TW has the highest concentration with $64*10^3$ particles/cm³, and WALO has a concentration of $51*10^3$ particles/cm³.

PRE-RCM 16 results revealed that the highest PM levels were observed after 4 h of ultrasonic diffuser use with TWOL PM10, PM2.5, and PM1 being at 562 µg/m³, 452 µg/m³, and 253 µg/m³, respectively. The PM number began to increase after just 2 h of ultrasonic diffuser use. However, the TW PM1, PM2,5 and PM10 levels were lower, as can be seen in Figure 7, they still exceeded the recommendations of The European Agency for Safety and Health at Work (EU-OSHA) (Von Hahn, 2022) into 2 h of ultrasonic diffuser work.

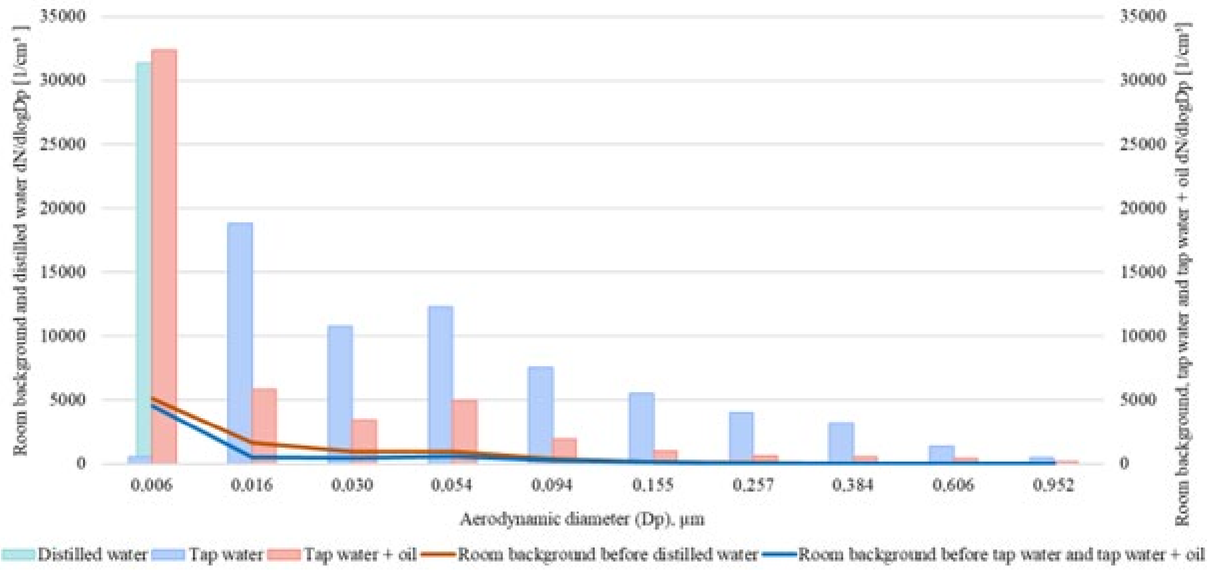

Figure 6 ***Particle size distribution (ELPI+) after ultrasonic diffuser use (summer season)***

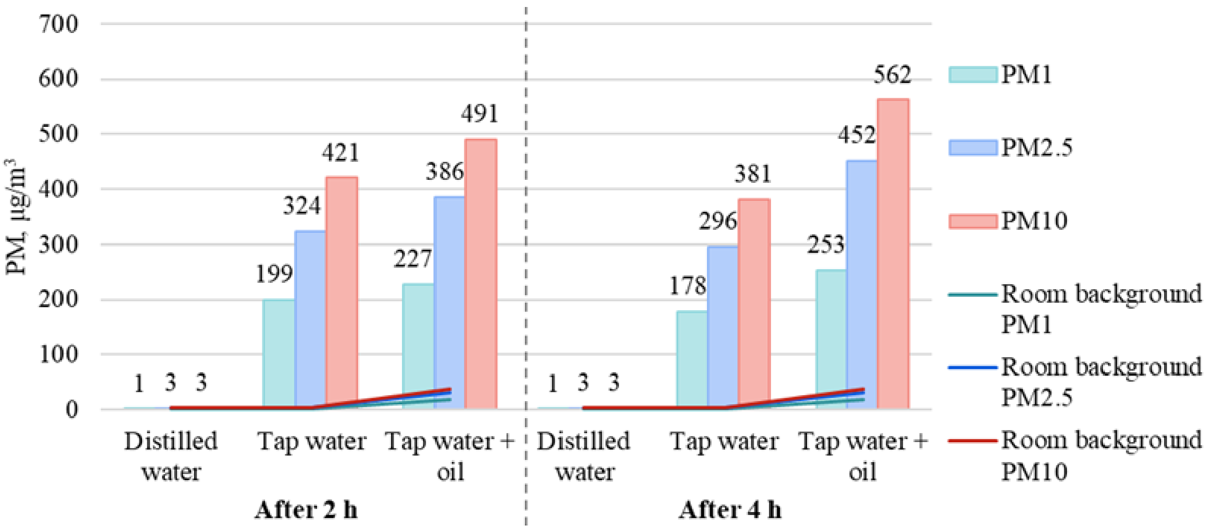

Figure 7 ***Particle size distribution (PCE-RCM 16) after ultrasonic diffuser use (summer season)***

Humidity

How it can be seen Figure 8, the most significant rise in relative humidity was recorded during summer season using WALO, achieving 53% relative humidity after 4 h. In contrast, the winter season reached its peak with TW. Overall relative humidity levels during the winter were consistently lower than during the summer season. It's important to note that manufacturers also mention that using DW can reduce the humidifying effect of ultrasonic diffusers. The data shows that, compared to control measurements, the use of DW over a 4-hour period had minimal impact on relative humidity levels. However, considering other studies reporting increases in PM levels, a lower increase in humidification should not be a deterrent to using ultrasonic diffusers.

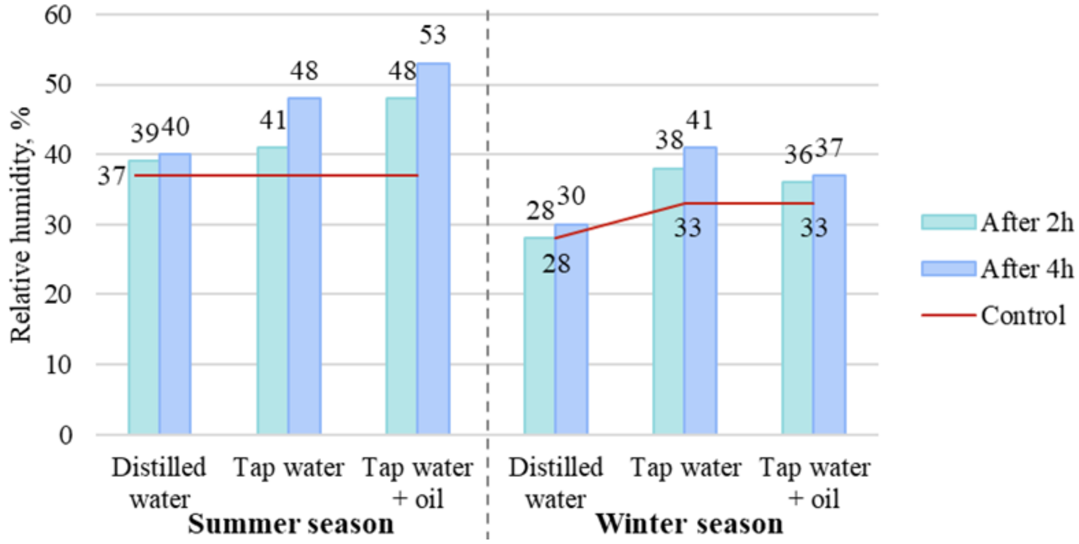

Figure 8 ***Relative humidity during ultrasonic diffuser use***

Temperature

Figure 9 represents changes of indoor temperature during the experiment. During both seasons the room temperature was higher after 2 and 4 hours of ultrasonic diffuser us with all types of water in comparison to the control (before ultrasonic diffuser use). In the summer season while using DW the temperature continued to increase after 2h, while with TW and WALO it started to slightly decrease. During winter while using DW and TW the temperature decreased, but with WALO it continued to increase. For a more detailed analysis of ultrasonic diffuser effect on room temperature more measurements are necessary.

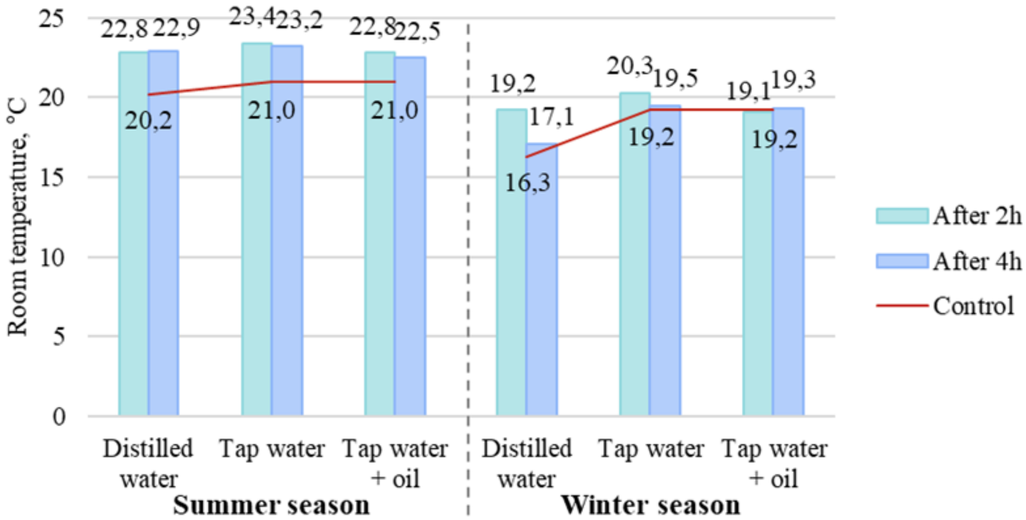

Figure 9 ***Temperature during ultrasonic diffuser use***

Conclusion

EU-OSHA (Von Hahn, 2022) have indoor air quality guideline values, which are set at less than 50 µg/m³ for PM10 and 25 µg/m³ for PM2.5 over a 24-hour average. Experiments involving the use of an ultrasonic diffuser with DW demonstrated that PM1, PM2.5, and PM10 levels can be maintained within acceptable ranges over a 4-hour period. However, these experiments also highlighted an increase in nanoparticle concentrations, for which current guidelines lack specific recommendations. Recently there have been concerns regarding particles smaller than 100 nm (0.1 µm). Using other type of water in the ultrasonic diffuser has shown to exceed the recommended particulate matter levels even after 4 hours.

In this study there was not an increase in microorganisms above the norms set by EU-OSHA (Von Hahn, 2022) <500 CFU/m³. However, other studies have shown that when an ultrasonic diffuser was used for more than 3 days, these standards were exceeded with the use of distilled water, boiled cooled water, and tap water. Given the current lack of specific recommendations for nanoparticle standards, we believe it's important to discuss the need for regular cleaning of the device and the use of distilled or deionized water.

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