ASSESSMENT OF INDOOR AIR HUMIDIFIER PERFORMANCE

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Abstract. One of the important microclimatic factors that affect the comfort or discomfort of the indoor environment inside buildings for the population or for stabled livestock is air humidity. Low air humidity can cause health problems by drying out mucous membranes, which are more easily attacked by diseases. Air humidity also affects the interior equipment of rooms and has an impact on their lifespan. In this research, five humidifiers were evaluated placed in a room measuring 4 x 2.6 x 2.5 m at distances of 1 m and 3 m from the humidifier. Humidification with a shower fountain humidifier increased the humidity ratio by only 0.6 and 0.7 $g \cdot kg^{-1}$, which was reflected in the smallest increase in relative humidity, only 1.9% and 2.8%. The activity of the rotary humidifier increased the humidity ratio by 1.2 $g \cdot kg^{-1}$ and 1 $g \cdot kg^{-1}$, and the relative humidity was increased only very slightly, only 5.8% and 5%. Better results were achieved with humidification using ultrasonic humidifiers. The humidifier without automatic regulation enriched the air with an increase in humidity ratio of 3.3 $g \cdot kg^{-1}$ and 3.8 $g \cdot kg^{-1}$, the increase in relative humidity was 17.9% and 23.5%. The humidifier with automatic regulation enriched the air with an increase in humidity ratio of 1.7 $g \cdot kg^{-1}$ and 2.3 $g \cdot kg^{-1}$, the increase in relative humidity was 9.8% and 13.0%. Humidification with both ultrasonic humidifiers resulted in a decrease in air temperature, which approximately corresponds to the adiabatic process used for air cooling. The highest humidification intensity was achieved with steam humidification. Steam humidification enriched the air with an increase in humidity ratio of 5.9 $g \cdot kg^{-1}$ and 5.1 $g \cdot kg^{-1}$, the increase in relative humidity was 27.8% and 24.5%. In this way, the highest relative humidity of 63.9% was achieved at a distance of 1 m from the humidifier.

Keywords: humidification, microclimate, steam, water, winter season.

Introduction

Since the energy crisis of the 1970s, measures have been taken to save energy in buildings, but at the same time, the symptoms of sick building syndrome (SBS) are becoming more common [1]. SBS is manifested by headaches, fatigue, respiratory and eye irritation, allergies and other illnesses, which in some cases lead to serious and severe cardiovascular and respiratory diseases [2]. Losses of work productivity and treatment of damaged health require increased costs that exceed the benefits associated with energy savings in buildings [3].

One of the important microclimatic factors that affects the comfort or discomfort of the indoor environment inside buildings for the population or for livestock is air humidity. Air humidity is also an important parameter according to which ventilation air flows are determined or verified in some cases. Excessive humidity is harmful in some cases. Health can also be worsened by inhaling harmful particles contained in water [4-6], water purity and quality are important [7].

Low air humidity is also harmful, which people have been complaining about for many years [8-12], and which can cause health problems by drying out mucous membranes, which are more easily attacked by diseases. Air humidity also affects the interior furnishings of rooms; if the air is too dry, furniture and other wooden parts of apartments and houses dry out, which affects their service life. Problems with low humidity are more pronounced, especially in the cold winter season, during the heating season, e.g. in Nordic countries with long winter seasons [13].

To achieve optimal humidity in the conditions of the cold winter period, when the air is usually dry, various humidification methods are recommended, based on different physical principles and using various technical methods and devices of different designs and parameters [14-17]. When applying humidifying devices and equipment, changes occur in the parameters of the indoor environment. For the evaluation of the operation of humidifiers, the achieved changes in the parameters of the indoor air are important, as well as the flow rate of the supplied water, by which the changes are achieved [18].

The aim of this work is to present the results of microclimatic research focused on assessing the function of air humidifiers (AHF) in the interiors of buildings. The results of this research can be useful for practical application in adjusting the humidity of indoor spaces, also as a theoretical basis for further research.

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Materials and methods

For this research, air humidifiers of different designs were used, tested in a room during the winter period. The following air humidifiers were evaluated: a shower humidifier (water fountain) with natural air flow (A), a rotary disc humidifier (B), a semi-automatic ultrasonic humidifier (C), an ultrasonic humidifier with automatic regulation (D), and steam humidification (E). Basic data on the humidifiers are summarized in Table 1.

Table 1

Basic data on the air humidifiers

Humidifier	Label	Operating principle	Water volume, dm^3	Power label, W
A	ZV 1b	Shower fountain	2	10
B	Klad Z 15653	Rotating disc	3	18
C	Boneco 7131	Ultrasonic	5	40
D	Boneco 7138	Ultrasonic, automatic	5	40
E	-	Water steam by boiling	1.8	600

Photos of humidifiers A, B, C and D are in the photographs in Figure 1. A conventional hotplate and a pot (not shown in Figure 1) with a diameter of 160 mm and a volume of 1.8 l were used to produce water vapor (humidifier E).

Fig. 1. **Tested humidifiers:** shower fountain ZV 1b (top left), humidifier with rotating disc Klad Z 15653 (top right), ultrasonic Boneco 7131 (bottom left) and automatic ultrasonic Boneco 7138 (bottom right)

To measure the microclimate parameters, an Almemo2590-9 measuring station and sensors (Ahlborn Mess- und Regelungstechnik GmbH, Eichenfeldstraße 1, 83607 Holzkirchen, Germany) were installed in the experimental room. The size of the room affects the suitability of using humidifiers in the room. The investigated humidifiers are mainly intended for smaller rooms. The natural air flow in the room gradually disperses the humidity throughout the space. In the cold season, large window areas can worsen the heat balance and lead to a decrease in the indoor temperature, thereby increasing the relative humidity of the air, but not affecting the humidity ratio. The size of the windows during a sunny day increases local heat gains in part of the room, which causes temperature unevenness and helps intensify the flow inside.

Temperature and humidity sensors FHA 646 were placed in representative locations of the experimental room measuring 4 x 2.6 x 2.5 m in a distance of 1 m and 3 m from the humidifier, with registration at 1-minute intervals. During the measurement, the outdoor air parameters were determined from an outdoor weather station: outdoor temperature t_e = 5.5 ± 0.3 °C and outdoor relative humidity RH_e = 70.4 ± 1.7%.

The sensors of the FHA 646 type have a range of application from -20 to 80 °C and from 5 to 98% relative humidity. The measurement range of the capacitive relative humidity sensor ranges from 0 to 100% with an accuracy of ± 2% in the range < 90% relative humidity at a nominal temperature of 25°C ± 3 °C.

The measured values were processed using Excel software. Based on the measured values of the air temperature t, °C and relative air humidity *RH*, %, the humidity ratio x, $g \cdot kg^{-1}$ was calculated according to equations (1) to (3), given in publication [18].

$$x = 0.622 \frac{RH \cdot p''_p}{p_a - RH \cdot p''_p}, \tag{1}$$

where x – humidity ratio, $g \cdot kg^{-1}$;
RH – relative humidity, %;
p_p'' – saturated water vapor pressure, kPa;
p_a – atmospheric pressure, kPa.

Saturated water vapor pressure was calculated according to equation (2).

$$\ln p''_p = \frac{1515 + 23.6t}{t + 236}, \tag{2}$$

where t – air temperature, °C.

Atmospheric pressure was calculated according to equation (3).

$$p_a = 101.3 \frac{1600 - H}{1600 + H}, \tag{3}$$

where H – altitude, m.

To measure the actual electrical power for humidification by individual humidifiers, a Silver Crest IAN 56861 measuring device, model EM 240-A FR, was used with the following parameters: input voltage 230 V ~, 50 Hz, max. permissible load 16 A ~, power indication range 0-3500 W, resolution 0.5 W and tolerance range ± 3%, ± 2 W.

Results and discussion

Table 2 shows the measured initial, final and calculated values of temperature *t* (°C) and relative humidity *RH* (%) of air in distances 1 m and 3 m by humidification with all tested air humidifiers.

According to equations (1) to (3), the humidity ratio x_e = 4.1 g kg^{-1} was also calculated for the outdoor air. The values of the indoor air in the experimental room at the beginning of the measurement were influenced by the thermal-humidity conditions after the air had transitioned to normal operating conditions, which was reflected not only in the higher temperature of the indoor air t_{i0} heated by internal heat sources, but also in the slightly increased water content (humidity ratio) in the air from the neighbouring rooms and corridors before the measurement, and thus in the higher humidity ratio x_{i0}. It was technically impossible to ensure absolute air exchange without the influence of the environment.

Table 2 shows the results of calculating humidity ratio *x* ($g \cdot kg^{-1}$) according to equations (1) to (3) for the initial and final measurement values. The resulting increment shows the amount of water vapor added to the air during 1 hour of humidifier operation.

Humidification with the shower fountain humidifier (A) ZV 1b increased the humidity ratio by only 0.6 and 0.7 $g \cdot kg^{-1}$, which was reflected in the smallest increase in relative humidity, only 1.9% and

2.8%. The activity of the rotary humidifier (B) Klad Z 15653 increased the humidity ratio by 1.2 g·kg^{-1} and 1 g·kg^{-1}, also here the relative humidity was increased only very slightly, only 5.8% and 5%. Better results were achieved with humidification with ultrasonic humidifiers.

The humidifier (C) Boneco 7131 without automatic regulation enriched the air with an increase in humidity ratio of 3.3 g·kg^{-1} and 3.8 g·kg^{-1}, the increase in relative humidity was 17.9% and 23.5%. The humidifier (D) with automatic regulation Boneco 7138 enriched the air with an increase in humidity ratio of 1.7 g·kg^{-1} and 2.3 g·kg^{-1}, the increase in relative humidity was 9.8% and 13.0%, which is less than the humidifier (C) without automatic regulation. Due to the automatic regulation of the humidifier (D) set to 60% at higher relative humidity, the humidification intensity was briefly reduced. Humidification with both ultrasonic humidifiers (C) and (D) resulted in a decrease in air temperature, which approximately corresponds to the adiabatic process used for air cooling.

The highest humidification intensity was achieved with steam humidification (E). Steam humidification enriched the air with an increase in humidity ratio of 5.9 g·kg^{-1} and 5.1 g·kg^{-1}, the increase in relative humidity was 27.8 and 24.5%. In this way, the highest relative humidity of 63.9% was achieved at a distance of 1 m from the humidifier.

Table 2

Initial, final and differential values of air temperature t (°C), relative humidity *RH* (%) and humidity ratio x (g·kg^{-1}) in distance L (m) after 1 hour of humidification by air humidifiers (AHF)

AHF	*L*, m	t_{i0}, °C	t_{iF}, °C	Δt_i, °C	RH_{i0}, %	RH_{iF}, %	ΔRH_i, %	x_{i0}, g·kg^{-1}	x_{iF}, g·kg^{-1}	Δx_i, g·kg^{-1}
A	1	24.4	24.8	0.4	36.0	37.9	1.9	7.1	7.7	0.6
	3	23.8	24.1	0.3	35.7	38.5	2.8	6.8	7.5	0.7
B	1	24.4	24.5	0.1	36.1	41.9	5.8	7.1	8.3	1.2
	3	23.7	23.7	0	38.1	43.1	5	7.2	8.2	1
C	1	24.1	23.7	- 0.4	37.2	55.1	17.9	7.2	10.5	3.3
	3	23.5	22.5	- 1.0	35.7	59.2	23.5	6.7	10.5	3.8
D	1	23.9	23.7	- 0.2	39.9	49.7	9.8	7.7	9.4	1.7
	3	22.9	22.8	- 0.1	41.2	54.2	13	7.4	9.7	2.3
E	1	24.1	24.7	0.6	36.1	63.9	27.8	7	12.9	5.9
	3	23.5	24.1	0.6	34.9	59.4	24.5	6.5	11.6	5.1

The air temperature curves measured at distances of 1 m and 3 m from the tested air humidifiers are shown in Figure 2. The decrease in the air temperature caused by water evaporation was most pronounced when ultrasonic humidifiers were used. On the contrary, during steam humidification (E), the air was heated. In the case of humidification with the shower fountain humidifier (A) ZV 1b, the temperature fluctuated slightly and increased slightly due to convection currents inside the room (sunlight from the window, etc.).

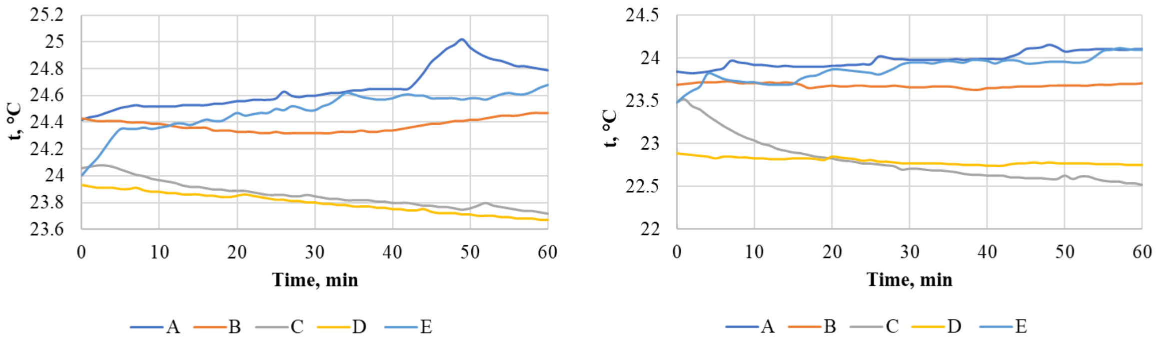

Fig. 2. **Course of air temperature *t*, °C for *L* = 1 m (left), for *L* = 3 m (right) during humidification**

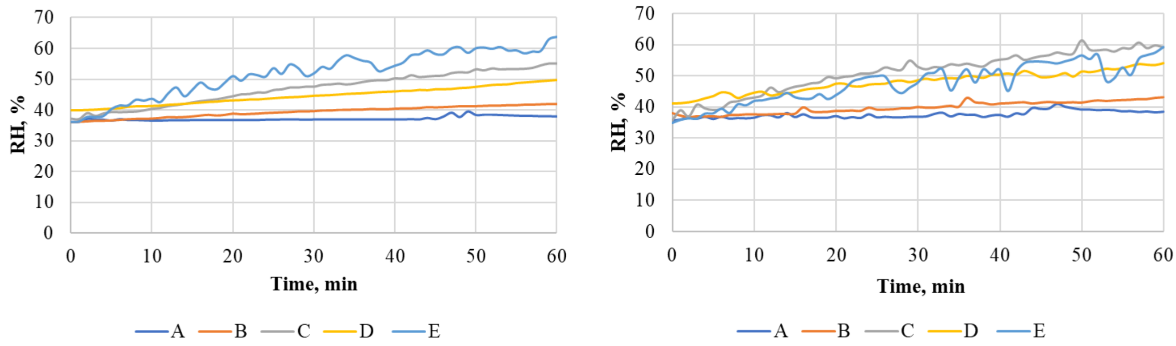

Fig. 3. **Course of air relative humidity *RH*, % for *L* = 1 m (left), for *L* = 3 m (right) during humidification**

Figure 3 shows the air relative humidity curves at these distances and Figure 4 the humidity ratio curves also at these distances for 1 hour. Both figures show a difference in the course of humidification, in accordance with the results given in Table 2. The relative humidity curves in Figure 3 and the humidity ratio in Figure 4 show greater humidity fluctuations at a distance of 3 m, which is caused by the influence of natural flow in the room.

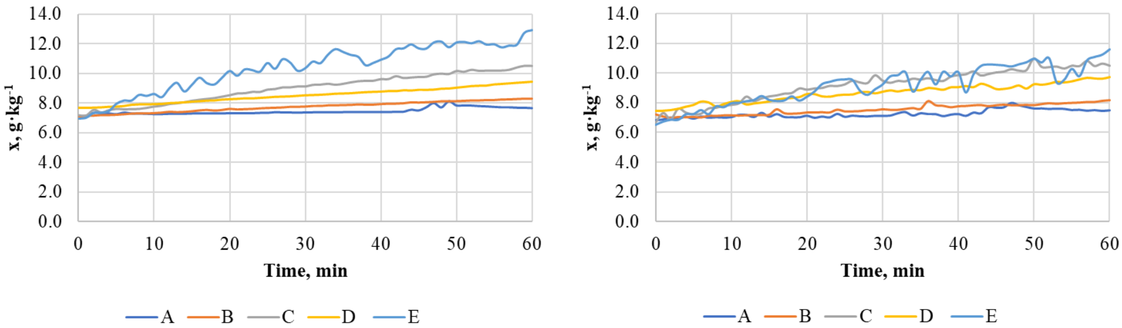

Fig. 4. **Course of humidity ratio *x*, g·kg^{-1} for *L* = 1 m (left), for *L* = 3 m (right) during humidification**

Table 3 shows the converted measurement results of the volume of water evaporated from the humidifier per hour *VW*, dm^3·h^{-1} and average real electric power during humidification *AREP*, W. Based on these results, specific electricity consumption was determined for supplying 1 dm^3 of water from the humidifier to the air *SEP*, W·dm^{-3}.

Table 3

Volume of water evaporated from the humidifier per hour *VW*, dm^3·h^{-1}; average real electric power during humidification *AREP*, W; specific electricity consumption for supplying 1 dm^3 of water from the humidifier to the air *SEP*, Wh·dm^{-3}.

Humidifier	*VW*, dm^3·h^{-1}	*AREP*, W	*SEP*, Wh·dm^{-3}
A	0.039	10.5 ± 0.7	269.2
B	0.167	18.3 ± 0.5	109.6
C	0.8	40.5 ± 0.5	50.6
D	0.23	29.1 ± 9.4	126.5
E	0.66	645.5 ± 4.2	978

In terms of specific electricity consumption for supplying 1 dm^3 of water from the humidifier to the air, the most efficient operation was performed by the ultrasonic humidifier (C) Boneco 7131 without automatic regulation. The automatic ultrasonic humidifier Boneco 7138 (D) had a lower average real electric power during humidification *AREP* = 29.1 ± 9.4 W, which was caused by an occasional automatic reduction in humidification performance for a short time, when the internal built-in sensor for measuring relative humidity in the device measured higher humidity in the vicinity of the humidifier.

Specific electricity consumption for supplying of water from the humidifier to the air *SEP* = 126.5 Wh·dm^{-3} was therefore higher.

The lowest real power *AREP* = 10.5 ± 0.7 W was found in the shower fountain humidifier (A), which has a low consumption, but also the lowest flow of evaporated water into the air, therefore the specific electricity consumption for supplying of water from the humidifier to the air *SEP* = 269.2 Wh·dm^{-3} is the second highest of all humidifiers.

The highest values of electrical energy consumption were measured for steam humidification (E). This method of humidification was partially worsened by conventional hotplate and pot heating, which has large energy losses not used for boiling water, but the energy is dissipated into the ambient air.

Conclusions

1. This research is beneficial for assessing the operation of several principles of indoor air humidification.
2. The increase in the humidity ratio is a suitable criterion for assessing the flow of water supplied to the air and for evaluating the function of the humidifier.
3. To achieve higher relative humidity of the air, the use of water fountains or a rotary disc evaporator is insufficient.
4. Ultrasonic humidifiers provide the necessary amount of water to the air to increase the relative humidity. Water purity and quality are important. Automatic regulation is effective for controlling the maximum achieved relative humidity in the room.
5. Very suitable for humidifying the air in rooms is the supply of water steam by boiling at the cost of higher energy consumption. A more efficient boiling system with less heat loss to the surroundings needs to be used.

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