# ANALYSIS OF WATER EVAPORATION FROM ODOR TRAPS USING 3D PRINTING TECHNOLOGY

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**Abstract**

The design of foul water stacks with direct ventilation in high-rise buildings is accompanied by hydraulic assessment, based on calculating pressure resistance of odor traps with the smallest water seal height. One of the important factors in this calculation is to consider evaporation of water from the trap, which significantly reduces its pressure resistance. This article deals with the experimental measurement of water evaporation from a trap, followed by detailed analysis.

**Keywords**

Odor traps, water evaporation, drainage, 3D printing

# 1 INTRODUCTION

The evaporation of water from an odor trap greatly affects its pressure resistance and must be considered when designing foul water stacks with direct ventilation in high-rise buildings. This is very important to prevent malfunction of the odor traps which can lead to the spread of unpleasant odors and viruses from the building's drainage system into the interior. In the 1980s, when this issue was intensively studied, the average daily water drop in the odor trap at an indoor air temperature of 20 °C was determined to be $h_0$ = 1,0 mm/day. However, this value was later adjusted to $h_0$ = 0,5 mm/day for two reasons:

- condensation of water vapor from the interior on the inner surface of the odor trap, which subsequently returns and replenishes the water vapor level ($h_{gain,zu}$) (1), was not taken into account,
- the effect of gases from the branch pipe with a high water vapor content which condenses near the odor trap and replenishes its level ($h_{gain,ks}$) (2), has not been taken into account [1], [2], [3].

Therefore, new experimental measurements were conducted to verify the average daily decrease of water in the odor trap caused by evaporation $h_0$ (mm/day) since it was assumed that the formerly established value may no longer be up-to-date. Currently, indoor spaces tend to be overheated and the average space temperature is often greater than 25 °C, which clearly influences the amount of evaporated water. Besides, urban population has changed, which affects the amount of water vapor in the sewerage systems (public sewerage and drainage in the building), which, by condensation, replenishes water in the odor traps. Sanitary appliances have also changed in the sense that they consume less water. Moreover, the experimental measurements were carried out in the 1980s in Russia where boundary conditions are different, and the established value has never been verified in our territory. Therefore, it must be stated that it is advisable to experimentally verify the said value for the current conditions.

Experimental measurements were carried out simultaneously at two locations in two types of buildings in Bratislava, namely a detached house (bathroom on the 2nd floor) in the Dúbravka distric, and a high-rise building of the Faculty of Civil Engineering (computer room on the 16th floor), STU, in the Old Town of Bratislava. The experimental measurements were carried out within 14 days (27/02/2024–12/03/2024) and this period was supposed to represent a longer period, during which sanitary appliances are not used for example, due to vacation. In order to be able to evaluate the experimental measurements well, 4 experimental odor traps had to be created using 3D printing technology. Water level drop in the odor trap $h_0$, relative humidity of the indoor air, and indoor air temperature were measured [4].

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# 2 METHODOLOGY

In the first step, it was necessary to invent the design and shape of the odor traps so that all the necessary data on water evaporation could be measured easily and clearly. For this reason, a mathematical analysis had to be carried out.

## Mathematical analysis

Fig. 1 shows the decrease of water in the odor trap due to evaporation when the sanitary appliance is not in use. Based on earlier research, it can be concluded from the graph that at an evaporation rate of 0.5 mm/day and assuming that no water is sucked out by the vacuum, the odor trap starts to lose its pressure resistance after 50 days of non-use of the fitting. After 100 days, it loses its function of preventing the spread of viruses and odors from the building's drainage system into the interior [1], [2].

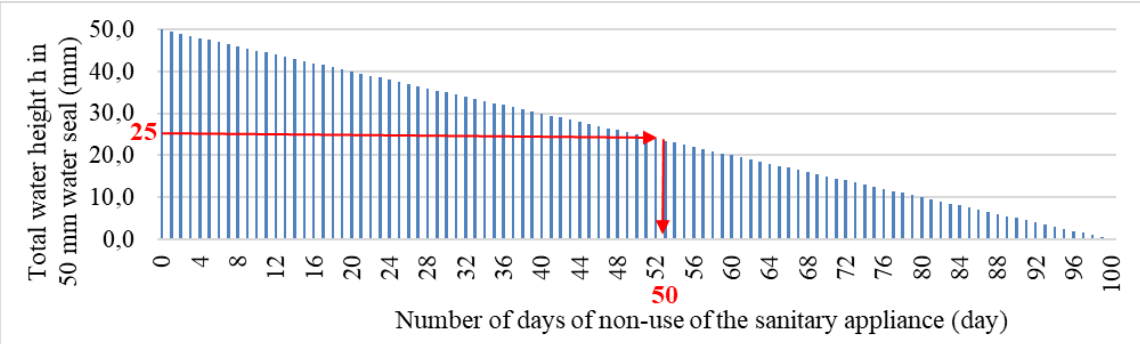


Fig. 1 Decrease of water in the odor trap due to evaporation when considering $h_0$ = 0.5 mm/day [Authors].

To be able to properly analyze the results of the experiment mathematically, it was necessary to make the 4 following samples of odor traps:

- sample V1 - allowed condensation of water vapor from the building's drainage system in the odor trap and at the same time condensation of water vapor from the interior on the inner surface of the odor trap (connected to the drainage), Fig. 2a,
- sample V2 - allowed condensation of water vapor from the building's drainage system in the odor trap (connected to the drainage), Fig. 2b,
- sample V3 - allowed condensation of water vapor from the interior of the building on the interior surface of the odor trap (not connected to the drainage), Fig. 2c,
- sample V4 - did not allow any water level rise in the odor trap (not connected to the drainage), Fig. 2d.

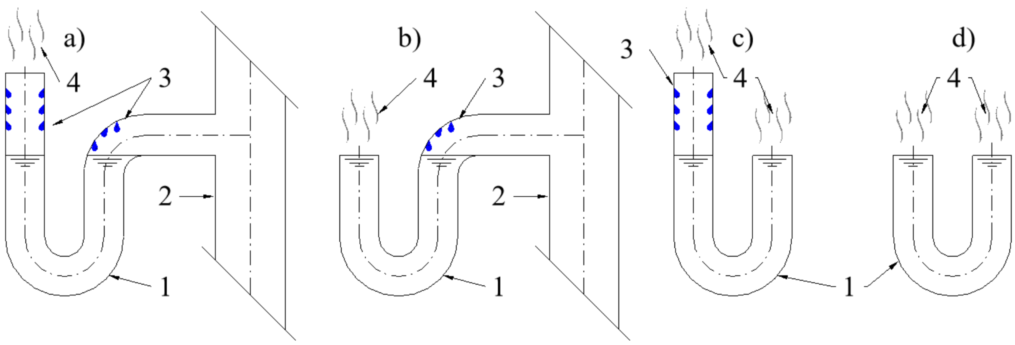


Fig. 2 Theoretical analysis of water vapor condensation and water evaporation from the considered samples of experimental odor traps; a) sample V1, b) sample V2, c) sample V3, d) sample V4 [Authors].

Since such experimental measurement with a detailed analysis of this sort has not been carried out to date, relevant formulas for this measurement had to be designed. These are formulas that compare the individual evaporation

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results of the samples in order to find out exactly how much water has evaporated, how much water has been replenished by condensation on the inner surface, and how much water has been replenished by condensation of water vapor. Water replenishment due to water vapor condensation from the drainage system in the near distance of the odor trap $h_{gain,ks}$ (mm) shall be calculated according to the following formula:

$$h_{gain,ks} = h_{drop,V4} - h_{drop,V2} \tag{1}$$

where $h_{gain,ks}$ is water replenishment due to water vapor condensation from the drainage system in the near distance of the odor trap (mm), $h_{drop,V4}$ is water drop in the odor trap V4 due to evaporation (mm), $h_{drop,V2}$ is water drop in the odor trap V2 due to evaporation (mm).

Water replenishment due to condensation of water vapor on the inner surface of the odor trap $h_{gain,zu}$ (mm) is calculated according to this formula:

$$h_{gain,zu} = h_{drop,V4} - h_{drop,V3} \tag{2}$$

where $h_{gain,zu}$ is water replenishment due to condensation of water vapor on the inner surface of the odor trap (mm), $h_{drop,V4}$ is water drop in the odor trap V4 due to evaporation (mm), $h_{drop,V3}$ is water drop in the odor trap V3 due to evaporation (mm).

To verify the experimental measurement, the following should be valid:

$$h_{drop,V4} = h_{drop,V1} + h_{gain,ks} + h_{gain,zu} \tag{3}$$

where $h_{drop,V4}$ is water drop in the odor trap V4 due to evaporation (mm), $h_{drop,V1}$ is water drop in the odor trap V1 due to evaporation (mm), $h_{gain,ks}$ is water replenishment due to water vapor condensation from the drainage system in the near distance of the odor trap (mm), $h_{gain,zu}$ is water replenishment due to condensation of water vapor on the inner surface of the odor trap (mm).

Verification of the calculation should come out with the smallest possible deviation (3). However it should be considered that e.g. in the odor shutters V4 and V2, water starts to condense on the inner surface after a certain period of time and therefore a small gain of $h_{gain,zu}$ (mm) is generated there. In order to avoid this gain, the odor stopper would have to be trimmed by a given drop of water on each day of the measurement.

## Experimental measurement methodology

No current standard [5] applies to the measurement of water evaporation from an odor trap. Thus, no measurement methodology is prescribed. For this particular experimental measurement, the following measurement methodology has been established:

- the odor traps were connected to the drainage system and placed at a specified location, Fig. 3; all connections had to be watertight and conform to EN 476 [6].
- the odor traps connected to the branch pipe were left connected for 2 days in order to stabilize water level in the odor trap due to hydraulic conditions; after this time, negative pressure in the branch pipe no longer drains water from the odor trap, at most it fluctuates it,
- after 2 days since the connection of odor traps to the drainage system, the measurement has started; water level in all the odor traps was checked every 24 hours at the same hour; water drop at the odor trap during holidays and weekends was calculated as the average of the measured water drop after the time when water drop could not be read,
- measurements were taken over 14 days, which represents an extended holiday period during which fixtures will not be used; relative humidity of the indoor air and the indoor air temperature of the room were recorded for the entire duration of the measurement according to ISO 7730 [4].

The tested odor traps V1 and V2 were connected to the existing building branch pipe at the location of the sink and odor traps V3 and V4 were placed under the sink, Fig. 3.

The samples had to be printed on a 3D printer because it was necessary to make them transparent and in 4 experimental designs, Fig. 4. Transparent odor traps are not produced and any modification of existing odor traps on the market would be almost unrealistic anyway. They are extruded from PLA (polylactic acid), which is a biodegradable material made from corn, potato starch or sugar cane. The nominal diameter of the odor trap was DN 40, the maximum water $h_{zu,tot}$ was 50 mm and they were equipped with a scale for reading the drop in water level.

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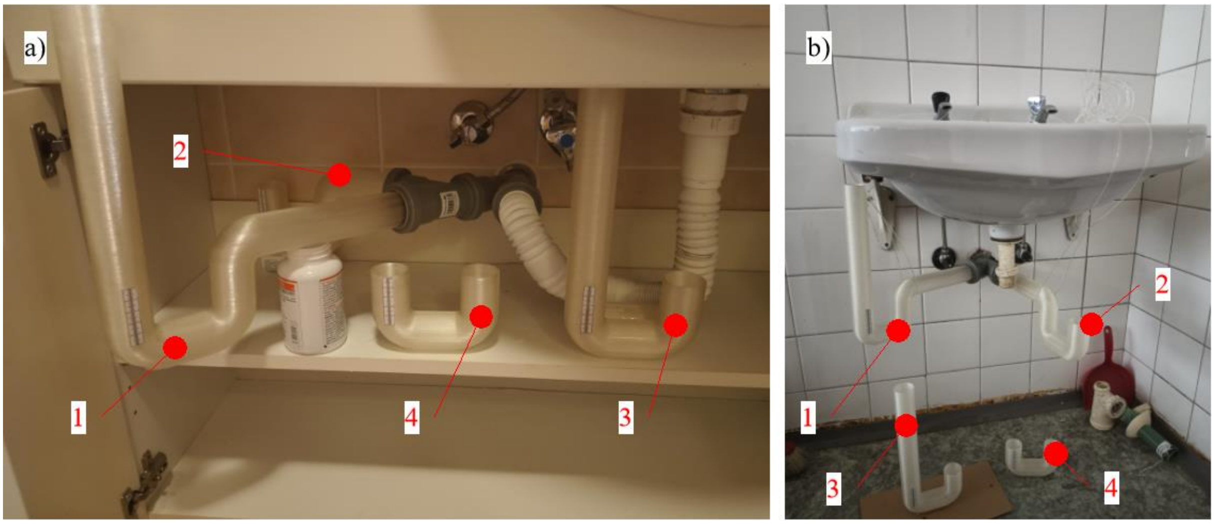


Fig. 3 Location of tested odor traps; a) in the bathroom of the detached house, b) in the high-rise building SvF, STU, 1 - sample V1, 2 - sample V2, 3 - sample V3, 4 - sample V4 [Authors].

The experimental measurement was performed simultaneously at two locations:

- detached house with two-storey - Bratislava, Dúbravka, outskirts of the city, bathroom, Fig. 4a,
- high-rise building with 23-storey building - Bratislava, Old Town, city center, classroom on the 16th floor, Fig. 4b.

The measurement started on 27/02/2024 at 2 p. m. and ended on 12/03/2024 at 2 p. m. in the computer room of the high-rise building. In the bathroom of the detached house, it started on 27/02/2024 at 8 p.m. and ended at 8 p. m. on 12/03/2024. The whole experimental measurement lasted 14 days.

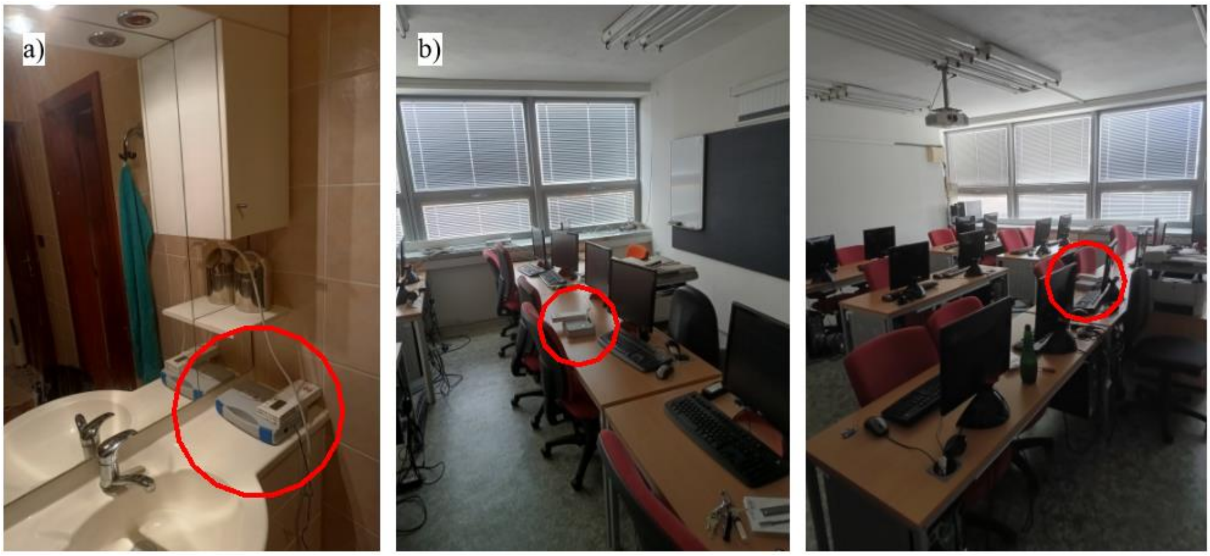


Fig. 4 Location of measuring devices; a) in the bathroom of the detached house, b) in the high-rise building of SVF, STU [Authors].

Indoor relative humidity $\varphi_i$ (%) and indoor air temperature $\theta_i$ (ºC) were measured using a Vaisala sensor type GMW90 and the measured data were stored on a HOBO type 4 data logger, Fig. 5. The range of the instrument in measuring air temperature is from -5 to +55 ºC with an accuracy of 10°C to 30°C ± 0.6°C. The instrument can measure relative humidity from 0% to 95% with an accuracy of ± 2.5% at 0–60%, ± 3.0% at 60–80%, ± 4.0 % at 80–95%.

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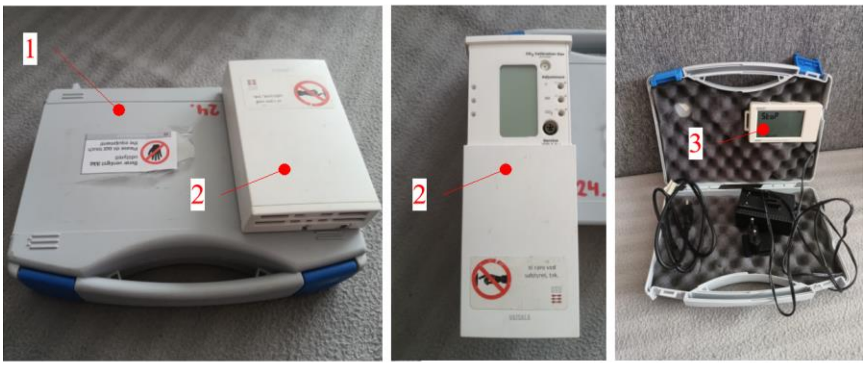


Fig. 5 Vaisala sensor on the HOBO data logger packaging; 1 - protective cover of the device, 2 - Vaisala sensor type GMW90, 3 - HOBO data logger type 4 [Authors].

# 3 RESULTS

The results of the experimental measurement of the water drop in the odor trap carried out in the detached house are shown in Fig. 6. During the measurement period in the bathroom of the house, the average relative humidity of the indoor air was $\varphi_i$ = 37.25 % and the average temperature of the indoor air was $\theta_i$ = 24.66 ºC, Fig. 7.

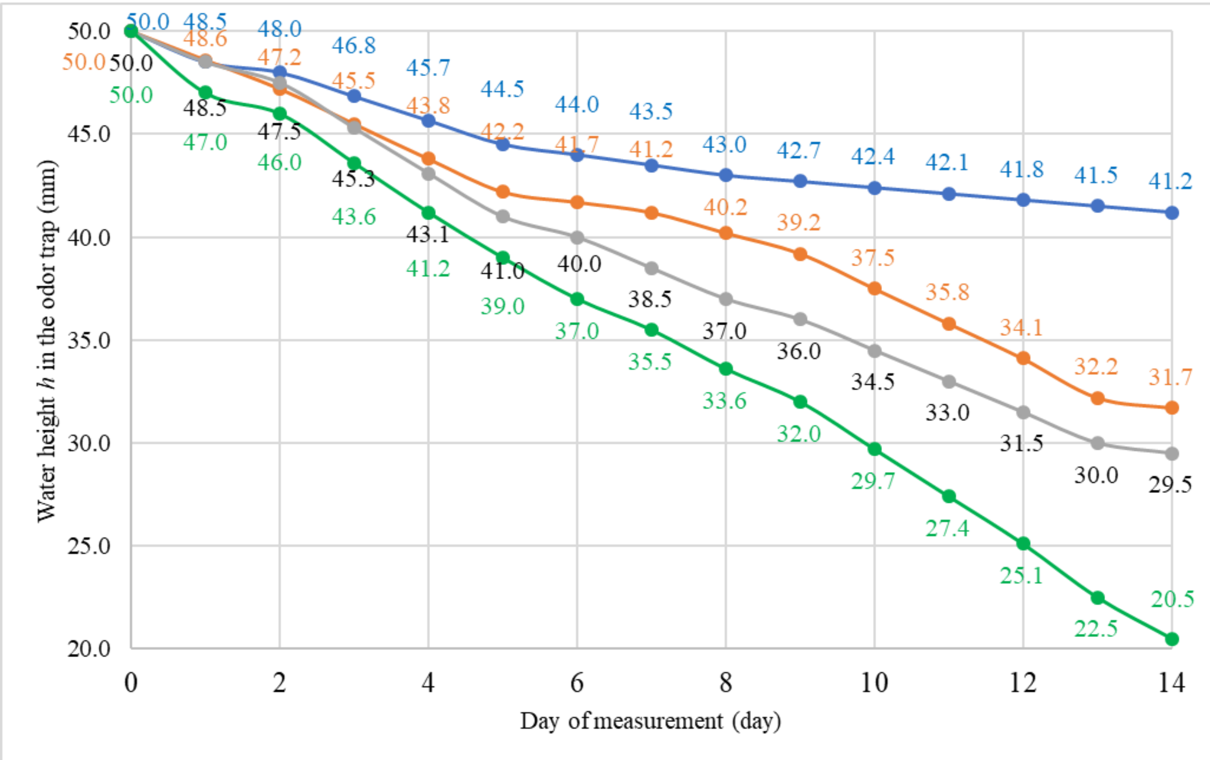


Fig. 6 Water loss due to evaporation in odor traps V1 - V4 located in the bathroom of the detached house;

■ sample V1, ■ sample V2, ■ sample V3, ■ sample V4 [Authors].

Fig. 6 shows the drop in water in the odor traps due to evaporation, which was located in the bathroom of the detached house. The average water drop in the odor trap V1 = 0.63 mm/day, V2 = 1.31 mm/day, V3 = 1.46 mm/day, and V4 = 2.11 mm/day. The average water recharge due to condensation of water vapor from the sewerage system near the odor trap was $h_{gain,ks}$ = 0.80 mm/day. The average recharge due to water vapor condensation on the inner surface of the odor trap was $h_{gain,zu}$ = 0.64 mm/day. The average measurement deviation was 0.036 mm/day.

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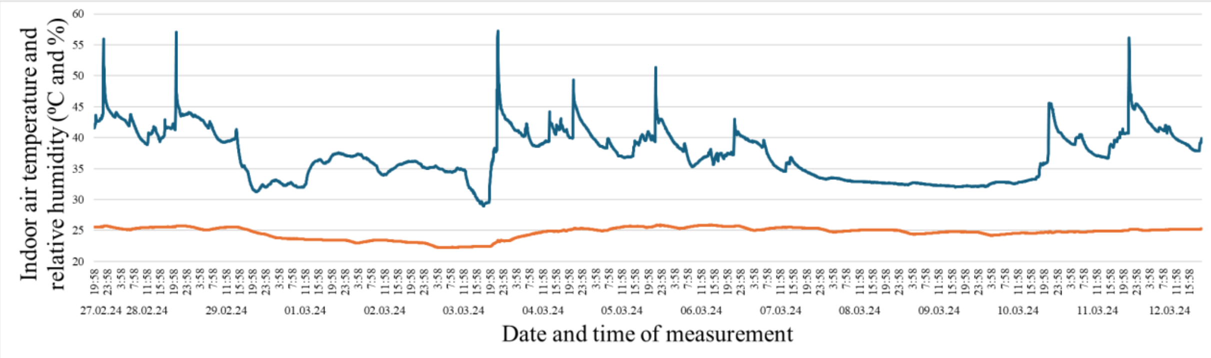


Fig. 7 Temperature and relative humidity in the bathroom of the detached house;

■ indoor relative humidity $\varphi_i$ (%), ■ indoor air temperature $\theta_i$ (ºC) [Authors].

The results of the experimental measurement of the water drop in the odor stopper carried out in the detached house are shown in Fig. 8. During the measurement period in the computer room in the high-rise building, the average relative humidity of indoor air was $\varphi_i$ = 32.20% and the average indoor air temperature was $\theta_i$ = 25.13 ºC, Fig. 9.

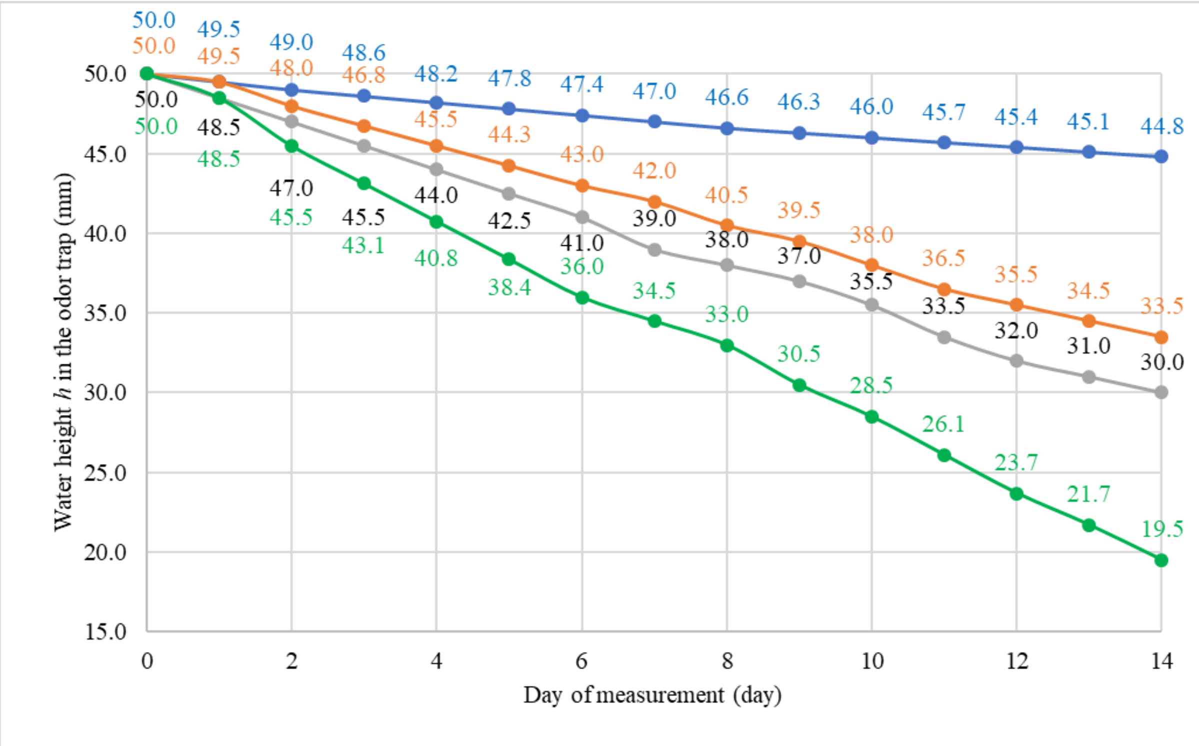


Fig. 8 Water loss due to evaporation in odor traps V1 - V4 located in the computer lab of the high-rise building of SVF, STU;

■ sample V1, ■ sample V2, ■ sample V3, ■ sample V4 [Authors].

The computer lab was minimally used during the measurement period, as can be seen from the measured indoor air temperature and humidity data. However, this did not affect the experimental measurements at all, as both the average temperature and humidity of the indoor air were within optimum values. The average water drop in the odor cap V1 = 0.37 mm/day, V2 = 1.16 mm/day, V3 = 1.43 mm/day and V4 = 2.18 mm/day. The average water recharge due to condensation of water vapor from the sewer system near the odor trap was $h_{gain,ks}$ = 1.01 mm/day. The average recharge due to water vapor condensation on the inner surface of the odor lock was $h_{zisk,zu}$ = 0.75 mm/day. The average measurement deviation was 0.044 mm/day.

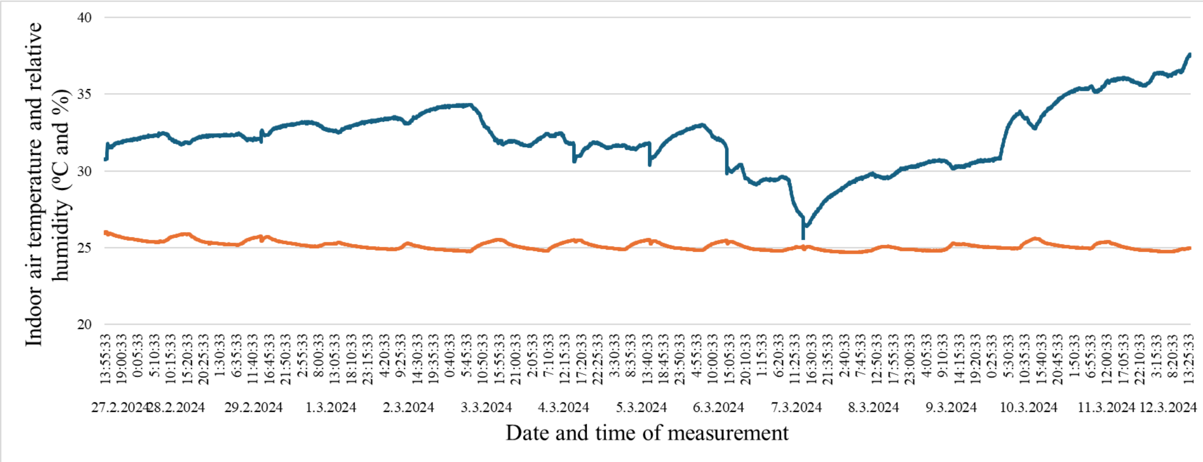


Fig. 9 Temperature and relative humidity in the computer lab of the high-rise building of SVF, STU [Authors].

■ indoor relative humidity $\varphi_i$ (%), ■ indoor air temperature $\theta_i$ (ºC)

# 4 DISCUSSION

Up to now, no experimental measurement of water evaporation from odor traps has been carried out in such detail. Many experimental measurements from abroad are made on measuring cylinders, without connection to the building's drainage system, and thus the measurement cannot be analyzed in detail. Nevertheless, measurements on measuring cylinders allow a better analysis of different sizes of odor trap surface areas, and it could be valuable to perform such measurements with real odor traps.

Evaporation of water from odor traps forms an essential part of the calculation of their pressure resistance, which plays an important role in the design of direct-vented foul water stacks in high-rise buildings. From the experimental measurements, we can see (Tab. 1) that the interior spaces of the buildings are often overheated, especially the computer room of the SVF, which represents higher evaporation rates for the odor traps. From the measured data, we can see that the location of the detached house and also the volumetrically smaller drainage system of the building influenced the recharge of water due to condensation of water vapor from the drainage system of the building $h_{gain,ks}$. Although the average indoor air temperature in the computer room area of the high-rise building was higher, there was more water refill in this area due to condensation of water vapor on the internal surface of the odor trap. The probable cause of this phenomenon iss due to the fact that the detached house provided better air exchange in the space. The results of this experiment are largely related only to the given location, in this case the city of Bratislava. In the future, it would be interesting to similarly test odor traps in other locations and compare to what extent the public sewerage system influences water recharge, as it contains the largest amount of water vapor.

Tab. 1 Summary of the measured data of the experimental measurement [Authors].

| **Building type** | **Location** | **Average indoor air humidity $\varphi_i$ (%)** | **Average indoor air temperature $\theta_i$ (ºC)** | **Average water recharge $h_{zisk,pcs}$* (mm/day)** | **Average water recharge $h_{zisk,zu}$** (mm/day)** | **Average measurement deviation (mm/day)** |
|---|---|---|---|---|---|---|
| **Detached house** | Bratislava - Dúbravka | 37.25 | 24.66 | 0.80 | 0.64 | 0.036 |
| **High-rise building** | Bratislava - Old Town | 32.20 | 25.13 | 1.01 | 0.75 | 0.044 |

* condensation of water vapor from the building's drainage system in the odor trap,
** condensation of water vapor from the interior in the odor trap.

# 5 CONCLUSION

The objective of the experimental measurements described in the introduction of this paper was met and also well-evaluated mathematically, which was greatly helped by 3D printing and the variability of the odor trap samples used. Based on the experimental measurements mentioned, it can be stated:

- the value ofwater evaporation of 0.5 mm/day in the calculation of the pressure resistance of odor traps for high-rise buildings located in city centers appears to be a safe value and, based on experimental measurements, this value was approximately 0.4 mm/day,
- for buildings with a lower number of stories, located in more distant parts of the city, it is recommended to use the value of 0.6–0.7 mm/day for the evaporation of water from odor traps, due to the lower volumetric flow of foul water in the sewers.

However, the correct choice of water evaporation from an odor trap will not ensure the correct design of the foul water stack in a high-rise building either. The currently established formulas for the calculation of hydraulic conditions in foul water stacks in high-rise buildings still have a large amount of data that needs to be checked and updated.

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