MOULD RISK ON WALL SURFACE IN PARTLY UNDERGROUND TECHNICAL ROOM

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Abstract
This conference article aims at the indoor climate in the technical room of an underground water reservoir. This indoor climate is specific by high relative humidity (average 75.2% r.h.) and low air temperature (average 13.6 °C). Therefore, this research study focuses on surface condensation and mould risk on the partly underground wall in the technical room. The experimental research combines long-term monitoring (22 months). Long-term of indoor climate and thermal numerical simulation. The experimental measurement shows condensation risk on the indoor wall surface, and the unsteady 2D numerical simulation in software CalculationArea 4.0e shows temperature fluctuation on indoor wall surfaces. Finally, the empirical VVT model predicts mould risk on the indoor wall surface for the over-terrain part in autumn and summer for the under-terrain part.

Keywords
Water reservoir, experimental measurement, numerical simulation, high relative humidity, mould risk

1 INTRODUCTION

The indoor climate in a technical room of an underground water reservoir is specific by high air relative humidity. This combination of high relative humidity and temperature increases condensation risk of air humidity on cold indoor wall surfaces and mould risk. This technical room uses weakly heating for energy efficiency. The mould risk in indoor climate is a research topic in many scientific studies. For example, Xues Y. et al. [1] on hygrothermal numerical simulation in software COMSOL Multiphysics over 12 months shows mould risk on the indoor wall surface in China. Johansson P. et al. [2] use experimental measurement (over 36 months) of un/organics specimens, and this experimental data compares with a different prediction model for mould risk. Hansen T.K. et al. [3] long - term experimental measurement in a historical building shows mould risk by the VVT model in the air gap between the historical wall and internal additional thermal insulation. Menneer T. et al. [4] in the indoor climate of bed/living room (300 rooms over 12 months) show mould risk by questionnaire method (the parameter is a smell and visibility of mould). This research study deals with the condensation and mould risk on the wall surface in the partly underground technical room.

Object description

The underground water reservoir in Mokre Lazce is part of the public plumbing system in Mokre Lazce, Czech Republic. This reservoir includes a partly underground technical room with a terrain entrance and an underground water tank. This underground water tank with volume of 1520 m³ compensates the peak water consumption (hydraulic stability) in the public plumbing system. The construction system of the water reservoir is reinforced concrete in the under-terrain part and ceramic bricks in the over-terrain part. The plan size of 6.0 × 5.5 m and height of 8.1 m creates the technical room with a net volume of 267 m³, see Fig. 1.

The ventilation turbine LOMANCO (DN 200 mm) with an airflow rate of up to 590 m³ per hour (depending on wind speed) supports natural ventilation of indoor climate. This indoor climate in the heating season heats the electrical heating element (input power 2000 W) with the set-point temperature of 10 °C. The technical staff occasionally visits (once a week) the technical room. Nevertheless, this user profile is not applied.

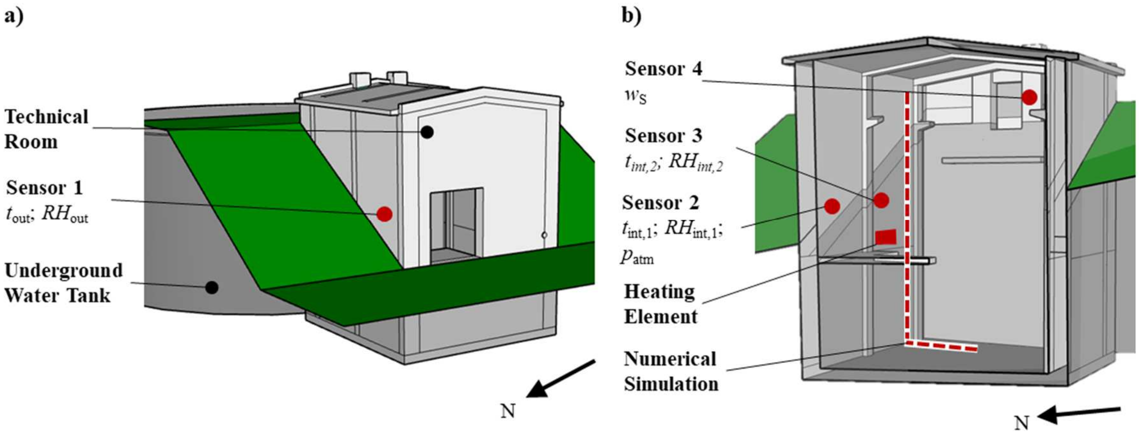

Fig. 1 a) Outer view on model of the underground water reservoir with a terrain entrance.
b) Vertical section of technical room and position of sensors.

2 METHODS

This research combines long-term experimental monitoring of indoor climate in the technical room with the thermal numerical simulation.

Experimental Measurement

The long-term measurement over 22 months includes the hygrothermal record of indoor and outdoor climate from January 2020 to October 2021 at hourly time-step. The hygrothermal measurement records data-logger records data-logger NETATMO with sensitivity ±0.25 K for air temperature and ±5.0% for relative humidity. The location of four hygrothermal data-loggers is listed below.

- **Sensor 1** records outdoor air temperature t_{out} °C and relative humidity RH_{out} % in hourly time step on the north facade of the water reservoir.
- **Sensor 2** records indoor air temperature $t_{int,1}$ °C, relative humidity $RH_{int,1}$ % and the atmospheric pressure p_{atm} Pa in the hourly time step on the switchboard near the entrance door.
- **Sensor 3** records indoor air temperature $t_{int,2}$ °C and relative humidity $RH_{int,2}$ % in the hourly time step above the heating element.
- **Sensor 4** records flow speed w_S m/s on the wall ventilation grille of ventilation chimney with ventilation turbine.

The outdoor climate in the numerical simulation uses the hygrothermal record of Sensor 1, see Fig. 1. The indoor climate in the numerical simulation uses a hygrothermal combination of Sensor 2 and Sensor 3, see Fig. 1. The hygrothermal interaction of Sensor 2 with Sensor 3 is plotted for indoor air temperature (see Fig. 2a) and indoor air specific humidity, see Fig. 2b. The linear regression between Sensor 2 and Sensor 3 is obtained for indoor air temperature in winter season (blue line) and summer season (red line), see Fig. 2a. The slope parameter of linear regression close to 1.0 (100%) shows the correlations between Sensor 2 and Sensor 3. The Sensor 2 is located on the switchboard and therefore shows higher air temperature of indoor climate. This hygrothermal combination from Sensor 2 and Sensor 3 in hourly average represents the space average in the technical room. The indoor air temperature is from 3.9 °C on 18th January 2021 to 21.9 °C on 21st June 2021, see Fig. 2. The outdoor air temperature is from -16.3 °C on 8th January to 39.3 °C on 19th June 2021, see Fig. 2. The ground temperature is sinus function between 7 °C on 15th February to 12 °C on 10th August.

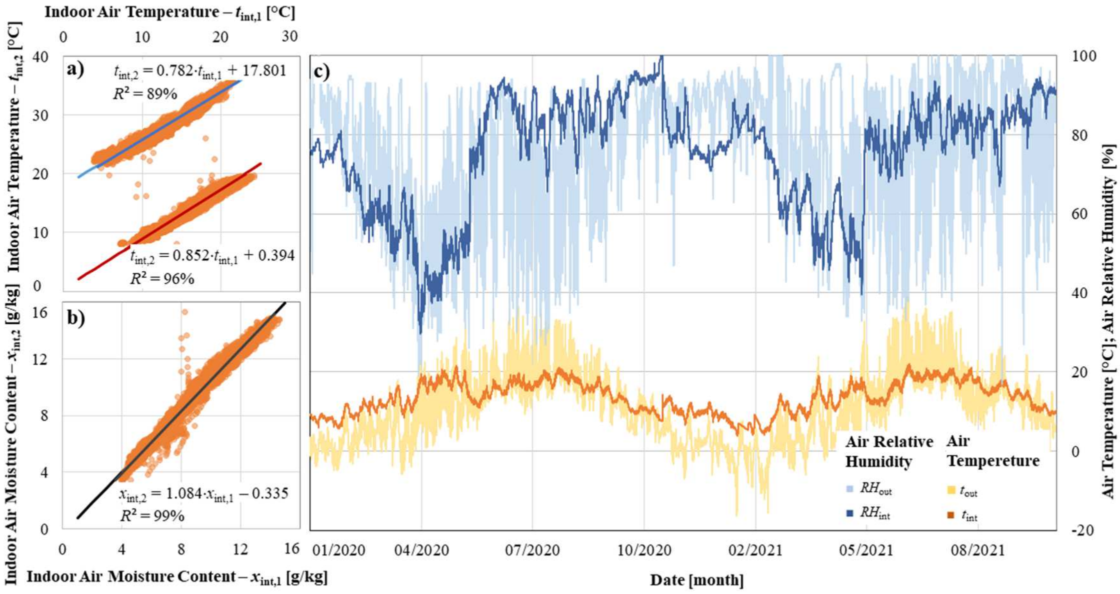

Fig. 2 a) The indoor air temperature of Sensor 2 with Sensor 3.
b) The specific humidity of Sensor 2 with Sensor 3.
c) Graph of hygrothermal measurement of indoor climate (dark colours) and outdoor climate (light colours).

Numerical Simulation

The unsteady thermal numerical simulation runs in the software Calculation Area version 4.0e (CalA 4.0e), more [5]. This calculation model uses the solution of the differential equation of thermal diffusion for two-dimensional unsteady temperature distribution, see equation (1):

$$\frac{\partial T}{\partial \tau} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \tag{1}$$

where T is the temperature distribution in K, time τ in seconds, material thermal diffusivity α in m²/s and space coordinates x, y in meter.

The calculation grid with a regular rectangular size of 150 × 150 mm includes idealized geometry. This idealized geometry assumes linear symmetry (real 3D on 2D model), constant and homogenous material characteristics, see Tab. 1, and the ideal orthogonal shape of building construction. This calculation geometry with 2 277 material cells includes the following boundary conditions, see Fig. 3.

- **Outdoor climate** is Robin-Newton boundary condition with variable outdoor air temperature and constant heat transfer coefficient 23 W/(m²·K), see[5].
- **Indoor climate** is Robin-Newton boundary condition with variable indoor air temperature and constant heat transfer coefficient 8 W/(m²·K) for the wall and 10 W/(m²·K) for the floor, see [5].
- **Ground temperature** is Dirichlet boundary condition with variable temperature in sinus function and heat transfer coefficient 1.15 W/(m²·K) as additional thermal resistance of 2 m ground depth.
- **Other edges** in calculation geometry assumes thermal adiabatic boundary condition.

The numerical solution is transient with variable indoor, outdoor and ground temperatures over 16 000 hourly time steps. The convergation criterion is the energy balance below 10^{-6} or 10 000 iteration cycles.

Tab. 1 Thermal material characteristics in calculation model.

Material	ρ [kg/m³]	Cp [J/(kg·K)]	λ [W/(m·K)]
Ceramic bricks and lime plaster	*1 800*	*900*	*0.96*
Ceramic bricks on cement mortar	*1 800*	*900*	*0.96*
Concrete	*2 100*	*1 020*	*1.58*
Reinforced concrete C25/30	*2 400*	*1 020*	*1.58*
Reinforced concrete C16/20	*2 400*	*1 020*	*1.58*
Ground	*2 000*	*920*	*2.30*

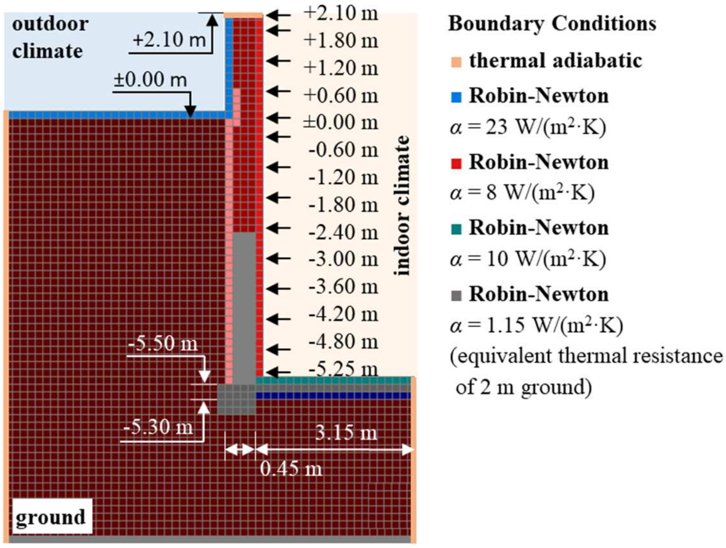

Fig. 3 Scheme of calculation grid, distribution of material characteristics, and boundary conditions.

Mould Risk Analysis

The mould risk is possible to evaluate by several models, for example, the updated VTT model (see [6]), Isopleth model (see [7]), and more [8], [9]. This research study uses the updated Finnish mould risk model (updated VTT model) for mould risk on the wall surface in the technical room. The updated VTT model defines four material sensitivity classes. RH_{min} is 80% *RH* for classes 1 and 2 and 85% *RH* for classes 3 and 4. Mould growth intensity is classified by seven levels of growth, starting from no growth (M = 0) and microscopic mould species present (M = 1) and ending with full visual mould coverage on the building material surface (M = 6). The mould risk expresses the mould index from equation (2) in the hourly time step [6]:

$$C_{mat}\frac{\mathrm{d}M}{\mathrm{d}t} = \frac{1}{7 \cdot \exp(-0.68\ln T - 13.9\ln RH + 0.14W - 0.33SQ + 66.02)} k_1 k_2 \tag{2}$$

where C_{mat} is the coefficients for different materials, d*M*/d*t* determines the rate of change of the mould index, *T* is the temperature in K, *RH* is the relative humidity in %, *W* is design parameter representing the wood type (0 = pine or 1 = spruce), *SQ* is the wood surface quality (0 = sawn surface, 1 = kiln dried quality), k_1 is the intensity coefficient and k_2 is the growth intensity.

3 RESULTS

This hygrothermal analysis of long-term experimental measurement, unsteady numerical simulation, and mould risk analysis by the updated VVT model shows condensation and mould risk on the wall surface in the partly underground technical room.

Temperature on Indoor Wall Surface

The surface temperature in 13 discrete points from level -5.25 m (under-terrain floor) to 2.10 m (peripheral wall over-terrain) shows unsteady temperature distribution on the partly subterranean wall, see Fig. 3. The indoor surface temperature (coloured lines) fluctuates with outdoor air temperature, see grey dot line in Fig. 4. This impact of outdoor air temperature on indoor surface temperature show also temperature differences related to the lowest point (-5.25 m), see Fig. 5. This chosen lowest point (-5.25 m) shows a minimal hygrothermal fluctuation in the time. Therefore, this point on level (-5.25 m) is the reference point. These curves of indoor surface temperature show the negative temperature difference in winter and the positive in summer. The fluctuation of indoor surface temperature decreases with the depth under-terrain and vice versa. The significant change in indoor surface temperature fluctuation is near terrain (see levels -0.60 m and -1.20 m in Fig. 5.).

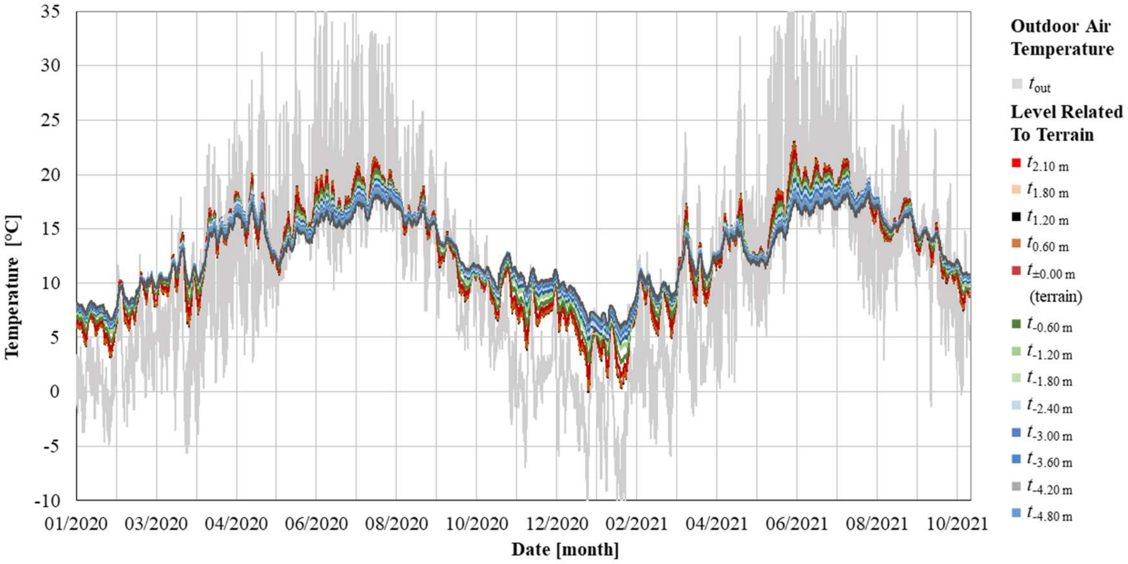

Fig. 4 Graph of outdoor air temperature (grey line),
and indoor surface temperatures in different levels (coloured lines).

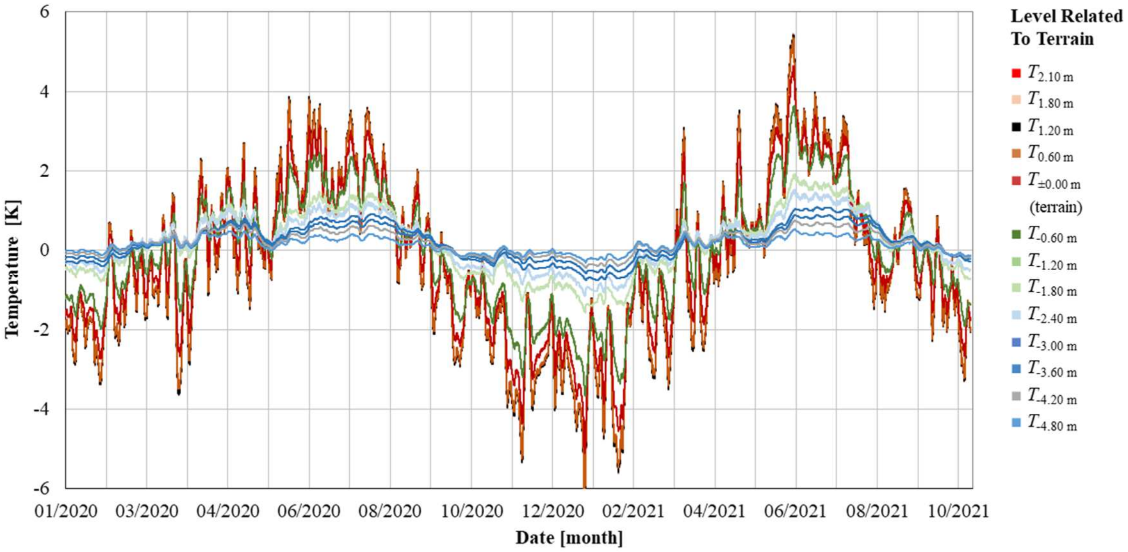

Fig. 5 Graph of indoor surface temperatures related to floor level (-5.25 m).
Red shades lines are located over-terrain and blue shades lines are located under-terrain.

DOI 10.13164/juniorstav.2024.24035

Relative Air Humidity on Indoor Wall Surface

The indoor air relative humidity with a long-term average of 75.2% is from 29.7% (at 3 a.m. on 9th April 2020) to 100% (on 11th and 12th November 2020). The condensation risk of air vapour on cold indoor wall surface is from 59 hours for level -1.80 m (under-terrain) to 1016 hours for levels 1.80 m and 2.10 m (over-terrain), more Tab. 2. The relative humidity on the wall surface is on the limit of 85% (mould risk) from June to February. All 13 discrete points are over the limit of 85% from June to July 2020, and October to November 2020, see Fig. 6.

Tab. 2 Duration time of relative humidity 100% on the indoor wall surface (condensation risk).

Discrete point [m]	*2.10*	*1.80*	*1.20*	*0.60*	*±0.00*	*-0.60*	*-1.20*	*-1.80*	*-2.40*	*-3.00*	*-3.60*	*-4.20*	*-4.80*	*-5.25*
Time duration [hour]	*1 016*	*1 016*	*1 010*	*937*	*409*	*136*	*60*	*59*	*69*	*135*	*168*	*236*	*387*	*709*

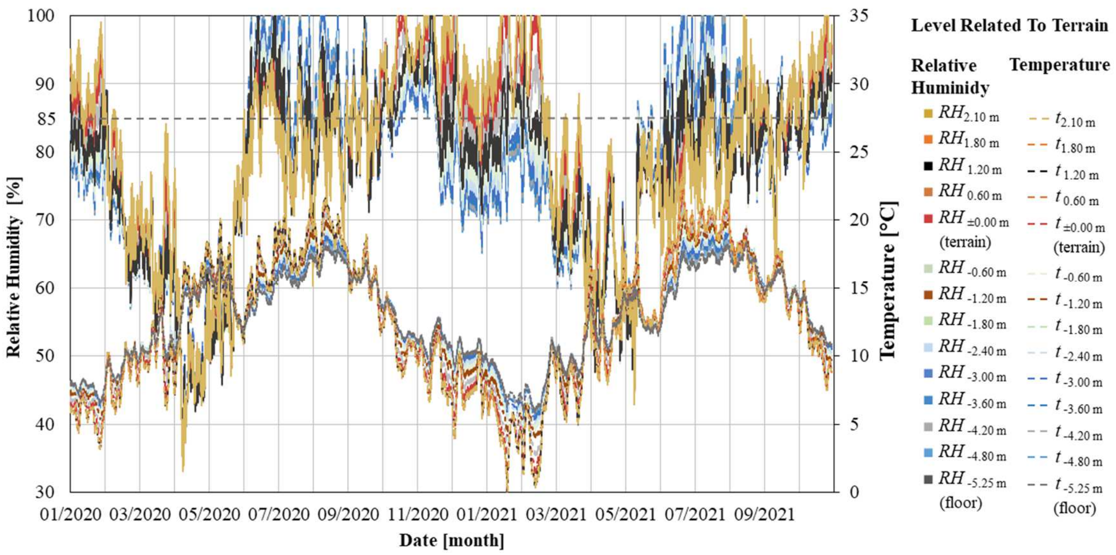

Fig. 6 Graph of indoor relative humidity and indoor temperatures on the wall surface. Brown shades lines are located over-terrain and blue shades lines are located under-terrain.

Mould Risk on Indoor Wall Surface

The index of mould risk under-terrain is up to 2.5 from June to July 2020. The under-terrain wall surface in summer is cold and increases the relative humidity on the wall surface. Oppositely, the over-terrain wall surface is cold in autumn and increases the surface relative humidity. The mould risk on cold indoor wall surface is from 4 878 hours for level -1.80 m (under-terrain) to 6 704 hours for levels 1.20 m, 1.80 m and 2.10 m (over-terrain), more Tab. 3. The index of mould risk over-terrain is up to 2.5 from October to November 2020. The mould risk is variable over time for the under-terrain part (in summer), and the over-terrain part (in autumn) see Fig. 7.

Tab. 3 Duration time of mould index on the indoor wall surface (mould risk).

Discrete point [m]	*2.10*	*1.80*	*1.20*	*0.60*	*±0.00*	*-0.60*	*-1.20*	*-1.80*	*-2.40*	*-3.00*	*-3.60*	*-4.20*	*-4.80*	*-5.25*
Time duration [hour]	*6 704*	*6 704*	*6 704*	*6 666*	*6 572*	*5 889*	*5 130*	*4 878*	*4 562*	*4 537*	*4 623*	*4 796*	*5 038*	*5 264*

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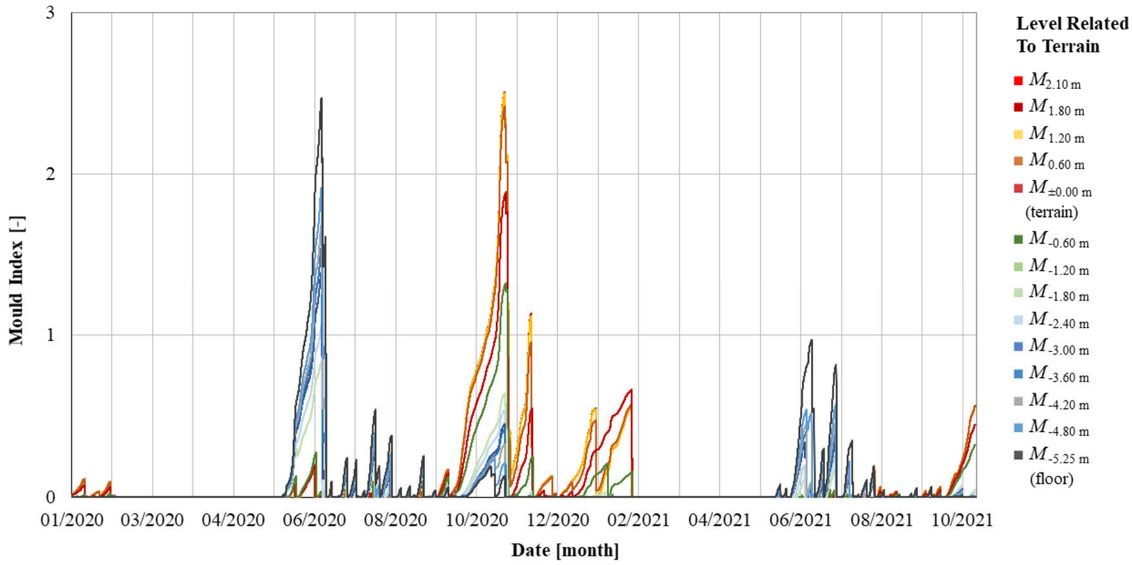

Fig. 7 Graph of predicted mould risk on the wall surface. Red shades lines are located over-terrain and blue shades lines are located under-terrain.

4 DISCUSSION

The indoor climate in the technical room of an underground water reservoir is specific by high relative humidity (avg. 75.2% r.h.) and low air temperature (avg. 12.1 °C). The hygrothermal analysis of experimental measurement shows condensation risk and temperature fluctuation on indoor wall surfaces. This condensation risk is influenced by the position of sensors, simplification of ventilation, idealization in the numerical model, and the hourly average of indoor climate. Nevertheless, this obtained hygrothermal parameters of indoor climate are applied for prediction of a mould risk. The impact of hygrothermal sensitivity of sensor on duration time of a mould risk is significant. Nevertheless, the effect of hygrothermal sensitivity of sensor on the seasonal mould risk (summer and autumn) is negligible. The heat capacity of the ground causes higher relative air humidity and lower surface temperature under-terrain in summer, as well as in scientific study by Yuan L. et al. [10]. The mould risk increases with relative humidity and the rapid growth of mould is over 84%, according to Shui Y. et al. [11]. The empirical predictive model VVT for the wall surface shows the mould risk for the over-terrain part in autumn and the under-terrain part in summer. This seasonal mould risk (summer and autumn) on the indoor wall surface agrees with the scientific study by Xue Y. et al. [1]. The mould on indoor wall surface in the technical room is not aesthetic, violate of hygiene standard, and increases risk of contamination of drinking water in the water tank. The current ventilation of technical room by ventilation turbine is not suitable. The new ventilation is possible to design by axial ventilator operated according to indoor/outdoor air specific humidity.

5 CONCLUSION

The mould risk on the wall surface of partly underground technical room is seasonal. The empirical model VVT predicts mould risk on the wall surface for the over-terrain part in autumn and summer for the under-terrain part.

Acknowledgement

The internal scientific grant FAST-J-23-8193 at the Brno University of Technology supported this research study. The other special thanks goes to the contractual research SR12957189L 2019 with the name Ventilation and Dehumidification of Reservoir objects financed by SmVaK a.s.

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DOI 10.13164/juniorstav.2024.24035