

THERMAL PROPERTIES AND OVERHEATING OF VENTILATED AIR CAVITIES UNDER PITCHED ROOF COVERINGS

Ondřej Pilný, Lubor Kalousek

Institute of Building Structures, Faculty of Civil Engineering, Brno University of Technology, Veverí 331/95, 602 00 Brno, Czech Republic

INTRODUCTION

Roofs are, from a constructional and thermal-technical point of view, one of the most important parts of buildings. From a historical point of view, we encounter sloping or steep roofs. At present and in the conditions of the Czech Republic, it is always possible to find a very similar roof composition, especially of the upper structure, which consists of the so-called additional waterproofing layer (hereinafter AWL), battens and roofing. Thanks to battens, a ventilated air cavity is created. This space serves for the drainage of infiltrated water and for the prevention of condensation of water vapor. Thus, it can affect the durability of the roof itself and can also significantly affect, by its very nature of the i.e. open-air cavity, the thermal-humidity flow of the roof structures. It is therefore a completely critical mechanism responsible for the proper functioning of the roof. As for the design of this cavity, the detailed calculation is very complicated and complex [1]. Therefore, in common practice the problematic itself is approached purely as a norm matter [2], which considers the assumption that the cavity has the same properties as the external environment. However, this approach is often inaccurate for more complex roofs and does not correspond to the real behavior and characteristics of these spaces [3] [4]. It is therefore necessary to examine the properties of these cavities more thor-

oughly, especially with respect to the growing requirements for thermal insulation properties and increasingly extreme temperature fluctuation [5].

This paper describes a full-scale experiment performed on a real object, where sensors are installed in the relevant critical places of the roof cladding composition, including the critical air cavity, and the thermal-humidity flow and state of this environment is monitored. The roof cladding is oriented sharply to the south and its slope is 30°. The composition and dimensions of the air cavity are in accordance with the Czech Technical Standard [2]. The roof has heavy structure with thermal insulation over rafters. For an accurate description of the experimental structure, the measuring system and its installation, see [6]. At the same time, the boundary conditions of the exterior are monitored. The paper also focuses on the analysis of the data using appropriately selected software and verification of the hypothesis that this cavity does not behave as an external environment whose parameters are attributed to it and aims to prove that in critical months the cavity can both negatively and positively affect the heat transfer mechanism.

METHODOLOGY

Data collection of thermal-humidity of the air cavity and the external environment – For a data collection, a measuring system [6] consisting of thermocouples, humidity sensors and data loggers is installed in the roof of the experimental building. To monitor the parameters of the cavity, the thermal-humidity sensor is installed, see Figure 1. Due to the importance of the external environment parameters, data from the meteorological station CHMI B2POHO01 [5] located near the experimental object are used. To determine the complex behavior of the cavity together with the influences of the external environment, thermocouples are installed in critical places, see Figure 2 – 4. The sensor on the upper surface of the roofing is covered with a next layer of roofing to eliminate data distortion by direct sunlight. The sensors are calibrated before installation.

Monitored parameters – The parameters that are monitored and compared by measuring system include the temperature and humidity of the exterior ventilated air cavity, which is further extended by the temperature on and under the roofing and the temperature on AWL. CHMI parameters that are monitored and compared include exterior air temperature, humidity and ground temperature. Data are recorded at 10-minute intervals.

Time horizon – To compare the benefits and negatives of the ventilated air cavity of the roof, the months January and July are selected according to [5], which statistically appear to be the coldest and warmest months when comparing temperatures in the Czech Republic from 2010 to 2019. Janu-

ary has an average temperature of -1.4°C and July 18.9°C. Furthermore, the critical norm date of 21st August is selected, on which the course of parameters is monitored in detail. [8]

Hypothesis demonstration – To prove the hypothesis of different parameters of the ventilated air cavity (hereinafter VAC) than the exterior, the program MS Excel, visual analysis and computational analysis are used, which compares the average values of temperature and humidity on the individual days. If the temperature of the VAC in January is higher than the exterior air and ground temperature, temperature of the VAC in July is higher than the exterior air and ground temperature, humidity of the VAC in January lower than the air humidity and the humidity of the VAC in July lower than the air humidity, the hypothesis can be considered as proved. For further confirmation of the hypothesis, the norm day of 21st August is selected and detailed course of all monitored parameters according to monitored parameters paragraph is recorded and analyzed.

In the case of a norm day, the complex course of temperatures of all relevant parts of the upper structure of the roof is monitored due to the hypothesis of the effect of a cumulative temperature increase. The effect is associated with the specific heat capacity of the roofing and the radiation of heat back into the air cavity even in the case of cloudy days or night hours. This phenomenon hypothetically leads to the different behavior of the cavity under investigation.



Figure 1. Thermal-humidity sensor installed in air cavity [7]



Figure 2-4. Thermocouples on the AWL and on lower surface and upper surface of the roofing [7]

Table 1. Comparison of Different Parameters of Air Cavity and Air in January

Parameter	Air Cavity Temperature	Air Temperature	Air Cavity Humidity	Air Humidity
Average	0.6076 °C	-0.1000 °C	83.9641 %	90.3988 %
Max	24.3 °C	14 °C	98.3 %	100 %
Min	-11.2 °C	-9.2 °C	23.5 %	49 %
Average Deviation	3.6284 °C	2.2672 °C	8.9592 %	8.01917 %

Table 2. Comparison of Different parameters of Air Cavity and Air in July

Parameter	Air Cavity Temperature	Air Temperature	Air Cavity Humidity	Air Humidity
Average	27.0915 °C	19.3763 °C	54.7988 %	74.1113 %
Max	63.3 °C	33.7 °C	100 %	100 %
Min	6.2 °C	7 °C	9.6 %	26 %
Average Deviation	12.2972 °C	4.5122 °C	26.3877 %	20.6399 %

Figure 5. GRAPH OF THE COURSE OF TEMPERATURES AND HUMIDITY IN JANUARY

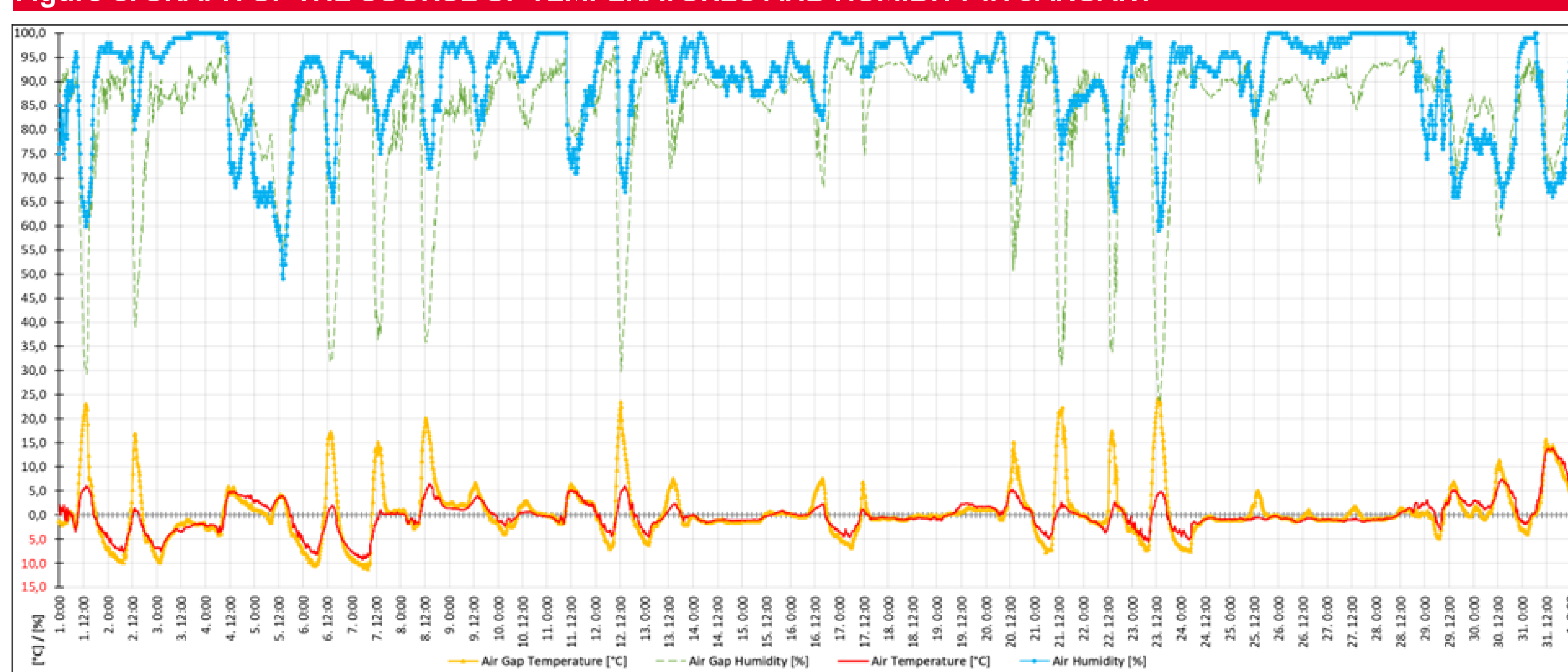


Figure 6. GRAPH OF THE COURSE OF TEMPERATURES AND HUMIDITY IN JULY

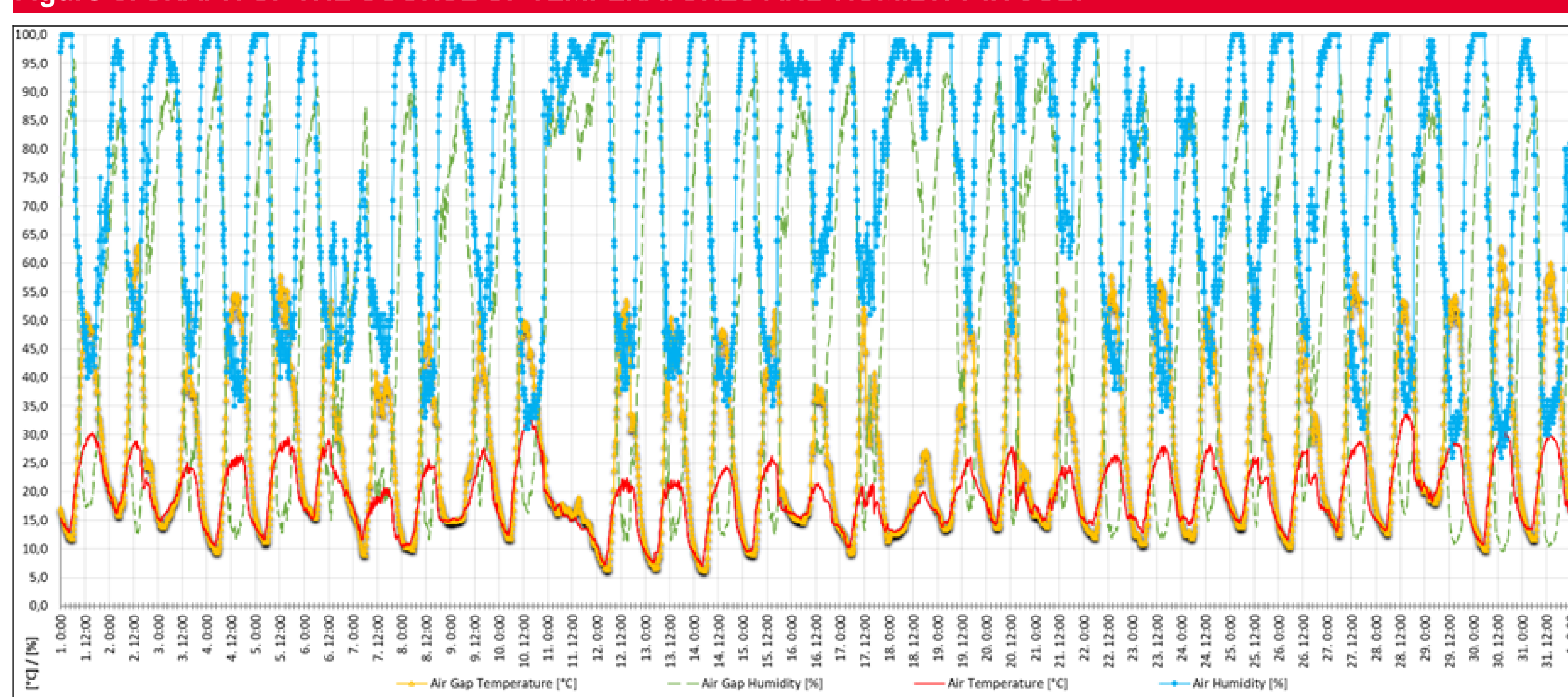
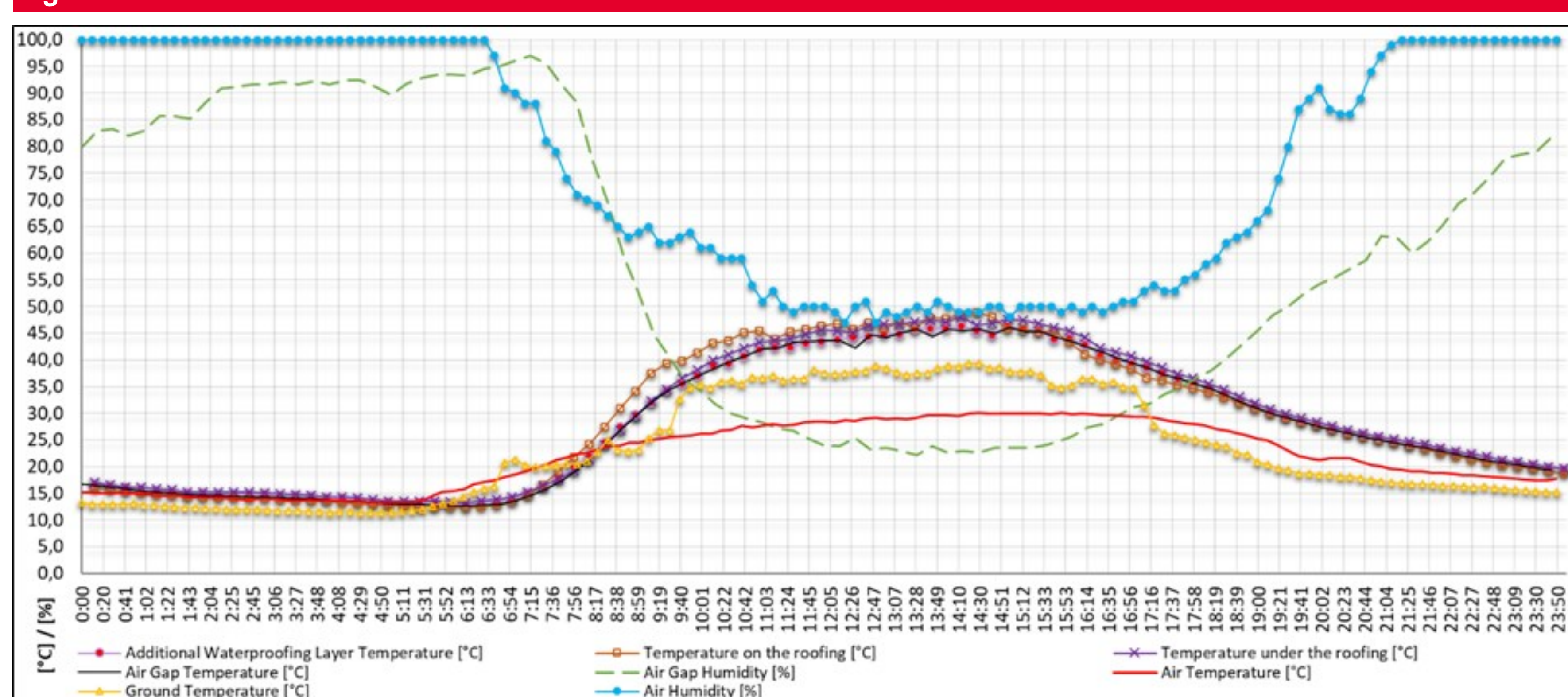


Figure 7. GRAPH OF THE COURSE OF TEMPERATURES AND HUMIDITY IN CRITICAL NORM DAY 21ST AUGUST



References
[1] Künzel, H. M.; Karagiozis, A. N.; Kehr, M.; Assessing the benefits of cavity ventilation by hydrothermal simulation. Proceedings Building Physics Symposium in honour of Prof. Hugo Hens, Katholieke Universiteit Leuven, Leuven, Belgium, 2008, p. 17–21. [4]
[2] ČSN 73 1901-1, 1901-2 Designing of roofs – Basic provisions, Roof with discontinuously laid roof covering, Praha ÚNMZ, 2020.
[3] Bunkholt, N.S.; Säwén, T.; Stockhaus, M.; Kvanne, T.; Gullbrekken, L.; Wahlgren, P.; Lohne, J. Experimental Study of Thermal Buoyancy in the Cavity of Ventilated Roofs. Buildings 2020.
[4] Gagliano, A.; Patania, F.; Nocera, F.; Ferlito, A.; Galesi, A.; Thermal performance of ventilated roofs during summer period. Energy and Buildings, Vol.49, 2012, p.611–618. ISSN 0378-778.

DISCUSSION

Analysis of the course of temperatures and humidity in January
As can be seen from the graph, see Figure 5, the air cavity temperature repeatedly exceeds the ambient temperature by several times during daily hours in the course of the month. In these cases, the cavity is heated by radiating of the roofing, which in turn obtains solar gains in clear and sunny weather. This effect is partially transferred to the night hours, when it is possible to count on the short-term radiation of the roofing and the associated positive effect of the cavity to reduce heat loss due to a lower temperature difference between the exterior and interior. At night and in the absence of solar gains, however, the effect is the opposite and, on the contrary, leads to cooling of the air cavity and thus increase of heat leakage, i.e. a negative effect. Furthermore, according to the graph see Figure 5, the humidity of the exterior is in most cases, including the transition period of day and night, higher than the humidity of the ventilated air cavity. Table 1 also shows the average temperature difference across the entire observed period, when a higher temperature inside the cavity is evident together with lower humidity. At the same time, it is clear that due to solar gains, this space shows higher deviations both in temperature and humidity.

Analysis of the course of temperatures and humidity in July
As can be seen from the graph, see Figure 6, the air cavity temperature again exceeds the ambient temperature several times during the daily hours, and partly also nightly hours throughout the entire month. The mechanism of solar gains is the same, but this time with negative effect that leads to overheating of the cavity and thus increase the negative heat gain from exterior. This effect is transferred into air cavity even into the late-night hours, see Figure 7, which prevents the cavity from cooling down and leads to a cumulative effect in the long run. According to the graph, the humidity of the exterior is again in most cases, including the transition period of day and night, higher than the humidity of the ventilated air cavity, which can be attributed to the much higher enthalpy of air in the cavity. Table 2 shows the maximum extreme temperature of the cavity, which exceeds the exterior parameters of the air by almost 30 °C. This temperature leads to overheating of the entire roof cladding. At the same time, a higher temperature and humidity deviation is again apparent, which is again caused by solar gains.

Analysis of the course of temperatures and humidity in critical norm day 21st August.
The graph, see Figure 7, shows the above-mentioned cumulative effect, which is amplified by high solar gains, which are then radiated into the roof ventilated air cavity almost all night. As we can also see, the temperature of the air cavity together with the temperatures of the roofing and the AWL is higher than the air temperature and than the ground temperature surrounding for the whole monitored day. As can be seen from the graph, this change occurs only for a short period of time during the early morning hours, when, in addition to temperature, there is also a change in the course of humidity due to the lower enthalpy of air in the cavity.

CONCLUSION

- Evidence from the discussion chapter:**
- The hypothesis regarding the different behavior of the ventilated air cavity of the roof is confirmed according to the previous chapter for both winter and summer period. In both cases, due to solar gains, the roofing heats up, which then radiates heat into the cavity itself, which increases the temperatures.
 - The hypothesis regarding the positive effect of the ventilated air cavity on the heat transfer mechanism in the winter months is confirmed. Due to the higher temperature in the cavity during sunny days, a minor temperature difference occurs and thus the heat loss from the interior is lower. This contributes, assuming the sufficient solar gains, to the stability of the interior temperature during the winter months and at low exterior temperatures.
 - The hypothesis regarding the negative effect of the ventilated air cavity on the heat transfer mechanism in the summer months is confirmed. Due to the higher temperature in the cavity caused by the radiation of the roofing with often high specific heat capacity, thanks to the material of its production, a cumulative increase in temperature can be observed from the graph of the summer month. This leads to a constant increase in the temperature of the upper structure of the roof, which leads to destabilization of the interior temperature in the summer months and the need to artificially cool the interior.

- The outcome depends on the following factors:**
- The roofing material, as well as the color of both upper and lower surfaces, can both positively and negatively affect the behavior of the ventilated air cavity. The high specific heat capacity of the roofing material can retain the heat for a longer time period, which is then radiated into the cavity and thus derive one of the above-mentioned mechanisms.
 - The exposure of the roof cladding to weather conditions has a direct effect on the functionality of the above-mentioned mechanisms.
 - Ventilation of the air cavity and the upper roof cladding has a direct effect on the functionality of the above-mentioned mechanisms. Theoretically, it can be expected that with a higher dimensioning of the ventilated air layer, or thorough ventilation, the development of temperatures in both mechanisms (cooling/heating) will slow down and thus approach the parameters of the exterior with temperatures and humidity. At the same time, it can be expected that if the roof is of a suitable slope, the resulting stack effect will positively stabilize the entire cavity mechanism. [9] [10]

It is therefore clear from the above text that the influence of ventilated air cavities of pitched roofs must be thoroughly investigated. Not only do they not approach the exterior parameters most of the time, the properties of which we attribute to them, but they can both negatively and positively affect the functionality of heat transfer through the roof and thus fundamentally contribute to both stabilization and destabilization of the indoor environment.

For future research in this field, it is necessary to thoroughly analyze the effect of the height of the ventilated air cavities, as well as the slope of the roof in their parameters. At the same time, it is also important to focus, in addition to the months listed here, on a comprehensive analysis of the behavior of these layers throughout the year and thus eliminate accidental weather conditions. Research should also address the issue of cavity behavior in the so-called transitional spring and autumn months, when the fluctuations in ambient temperature are very variable and unstable for a long time.

A completely separate direction for the future research should be the analysis of the influence of the roofing material itself and the tightness of the roofing locks and joints, which can again may have a direct effect on the functionality of the cavity mechanisms.

Acknowledgement
This paper has been worked out under the project No. FAST-J-20-6275 "Analýza hmotných konstrukcí šikmých střešů a jejich vliv na stav vnitřního prostředí".