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MONITORING OF MOISTURE CONTENT IN BRICKWORK WITH INFRARED THERMOGRAPH METHOD

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ABSTRACT

Moisture content in historical building structures is very negative factor causing degradation of physical and even mechanical properties of building materials. Degradation of physical and mechanical properties of building materials has effect on durability of the whole structure. Short time assessment and localization of moisture content in brickwork is very difficult (distribution of moisture and assessment of moisture rate). It is possible relatively precisely, non destructive and quickly asses distribution of moisture on area of building structure. The biggest advantage is easy creation of moisture map on structure in dependence on time.

Very quick and useful method for determination of moisture distribution in construction can be infrared thermography. This paper describes utilization of infrared thermograph method for monitoring of moisture content and distribution in historical masonry construction.

INTRODUCTION

The determination of the brickwork water content in situ is in practice relatively complicated. Destructive methods are used in general – the gravimetric and the CM methods are concerned – i.e. the moisture content of the brickwork is determined on specimens sampled from the structure. Further nondestructive methods are used – this concerns first of all the resistance, inductive and capacity methods. In these cases it is possible to determine the moisture relatively quickly, simply and with minimal impact of damage to the tested structure. (In the case of the resistance method a mild damage of the structure surface takes place by application of stab probes). The disadvantage of these methods is smaller accuracy, relatively limited field of measurement in the surroundings of the structure surface and the effect of brickwork salinity on the results of measurement.

The measurement is performed in all cases pointwise at selected places. If we want to get a general image about the moisture distribution in brickwork, it is necessary to realize the measurements in more points which are regularly distributed on the surface of the brickwork and it is necessary to construct following the results the so-called moisture map.

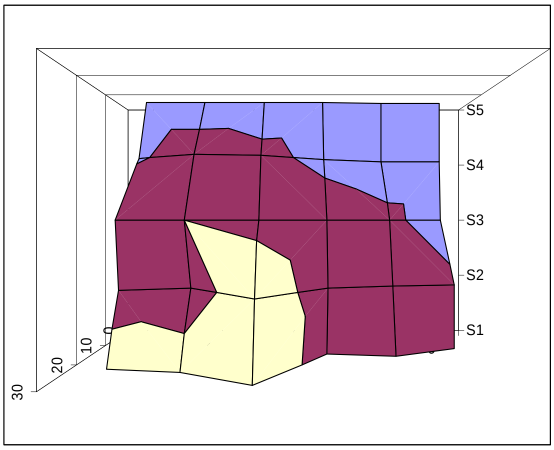


Fig. 1: The moisture map composed on the basis of measured moisture by means of the capacitive moisture indicator

It necessary to realize a relatively great number of measurements in order to receive the moisture map which has sufficient resolution. This is quite time-consuming. The higher resolution is necessary especially in the case when we are monitoring in the given structure the state of moisture and the change of its distribution (for instance during rehabilitation measures and the dehumidification of structures).

In the winter period, it is often possible, if there is sufficient temperature gradient between the outer and the inside environment, to use for preparing the moisture map the analogy between the temperature and the humidity field – the utilization of infrared thermography.

THE EFFECT OF MOISTURE ON THE HEAT CONDUCTION COEFFICIENT OF BUILDING MATERIALS

The effective value of the heat conduction coefficient of building materials is closely connected with the moisture content. The heat conduction coefficient λ [$W.m^{-1}K^{-1}$] of the humid material is determined by the heat conduction of the solid matrix, of fluid phases, of gaseous phases and their quantity, by phase changes and by the spatial distribution of phases. The heat conduction coefficient increases in general with the rising moisture content. The heat conduction coefficient of the dry, porous material can be simply expressed by the following relation:

$$\lambda_{dry} = \lambda_{mat} \cdot (1 - P) + \lambda_{vzd} \cdot P \tag{1}$$

where: λ_{dry} resulting heat conduction coefficient of the dry material [$W \cdot m^{-1} \cdot K^{-1}$],
λ_{mat} the heat conduction coefficient of the solid material without pores [$W \cdot m^{-1} \cdot K^{-1}$],
λ_{vzd} the heat conduction coefficient of air [$W \cdot m^{-1} \cdot K^{-1}$],
P the porosity [-].

In the case of material with moisture content, the air pores are gradually filled with water. The increase of the heat conduction coefficient is in the area of low (hygroscopic) humidity sharper. In the area of higher humidity the intensity of the heat conduction coefficient grow, usually decreases in dependence on the increase of the moisture content. The coefficient of the humid material can be simply expressed by undermentioned relations:

Inside the Area of Hygroscopic Moisture is $\lambda_{(w)}$

If we consider the heat bridges, which exist in the air-dry material under normal conditions by the effect of continual smallest pores filling by moisture w_{min} (see above) and the boundary hydroscopic moisture of the material $w_{h\ ma}$, we obtain for the heat conduction of the material matrix $\lambda_{mat(w)}$ [$W.m^{-1}.K^{-1}$] the following relation:

$$\lambda_{(w)} = \lambda_{mat\,(u,\varepsilon)} \cdot (1 - P) + \lambda_{vody} \cdot (w - w_{\min}) + \lambda_{vzd} \cdot (P - w) \tag{2}$$

where:

$$\lambda_{mat(w,\varepsilon)} = \frac{1}{\dfrac{1}{\lambda_{mat(w)}} + \dfrac{3\,\varepsilon\left(1 - \dfrac{w}{w_{\min}}\right)}{\lambda_{vzd}\,(1 - P)}} \tag{3}$$

$$\lambda_{mat(w)} = \frac{1}{\dfrac{1}{\lambda_{mat}} + \dfrac{w - w_{\min}}{\lambda_{vody}} + \dfrac{w_{h\max} - w}{\lambda_{vzd}}} \tag{4}$$

$$\varepsilon = \frac{1-2\upsilon}{E_m\ V_m}\int_{p_{c1}}^{0}\frac{w(p_c)}{w_{sat}} \qquad (5)$$

where:

υ	Poisson constant [-],
E_m	modulus of elasticity [Pa],
p_c	capillary pressure [Pa],
V_m	matrix volume in the volume of material [-],
w	moisture of the material [-],
w_{sat}	moisture of the material after saturation by moisture (in saturated state) [-],
$\lambda_{\mathrm{mat}\ (w,\varepsilon)}$	heat conduction coefficient of the material matrix, respecting material volume changes by the effect of its moisture content [W.m^{-1}.K^{-1}].

Outside the Area of Hydroscopic Moisture $\lambda_{(w)}$

After reaching the maximum of hygroscopic moisture $w_{h\ max}$ the capillary system is filled by moisture and the parallel system expressing the heat conduction is modified by the zigzag effect of the with moisture unevenly filled capillary system. This effect can be quantified by the introduction of the uniformity factor *R.* This factor can be determined on the basis of the porous system structural parameters. The following relation is valid in general (Meng 1994):

$$R = P_{rel}^{FD} \qquad (6)$$

where: P_{rel} relative porosity [-]

FD factor of the porous system dimensions [-]

The factor of the porous system dimensions is defined (Meng 1994):

$$FD = \frac{\Delta \log P}{\Delta \log r} \qquad (7)$$

In the area of similarity f, we can use for the calculation the relation:

$$R_f = w_f^{FD} \qquad (8)$$

The final value of the humid material heat conduction coefficient $\lambda_{(w)}$ [W.m^{-1}.K^{-1}] , behind the area of hygroscopic moisture can be expressed:

$$\lambda_{(w)} = \lambda_{mat\ (u)} \cdot (1-P) + \lambda_{vody} \cdot \sum_f w_f\ R_f + \lambda_{vzd} \cdot (P-w) \qquad (9)$$

where: f number of considered porous fractions, w_f. R_f is the autocorrelation function expressing the deviation of real pores from the parallel capillaries arrangement in the ideal model.

COMPOSITION OF THE MOISTURE MAP BY MEANS OF INFRARED SPECTROGRAPHY

During the thermovision measurements (building thermography) the incoming radiation in the area of infrared spectrum is evaluated and we obtain visible information (so-called thermogram) about the temperature distribution on the surface of the construction. The overwhelming majority of image forming systems (devices) uses as the signal for information transfer the electromagnetic waves in different parts of the spectrum. The device transforms the 3D scene into an image flow, which is able to evoke visual perception.

If the given structure is enough homogeneous, it can be assumed that the temperature field distribution on the structure should be uniform with mild decrease of temperature in corners.

If we determine on the surface of the structure significant areas of decreased surface temperature, we can expect that the moisture in these areas of structure is elevated.

Fig. 2: Photograph of the building structure surface with the moisture map in the lower part

It is possible to determine quickly by means of infrared thermography the surface temperatures and the temperatures distribution on the surface of the construction. The below presented figure shows that in the surrounding of the moisture map the surface temperature decreases. This is caused by the decrease of the side wall heat insulation properties as the result of elevated moisture content.

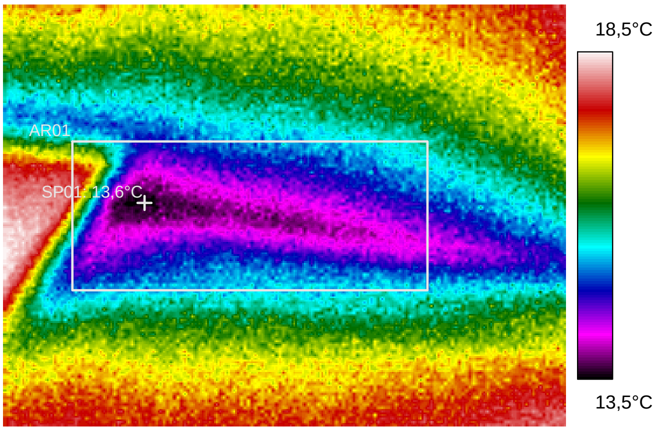
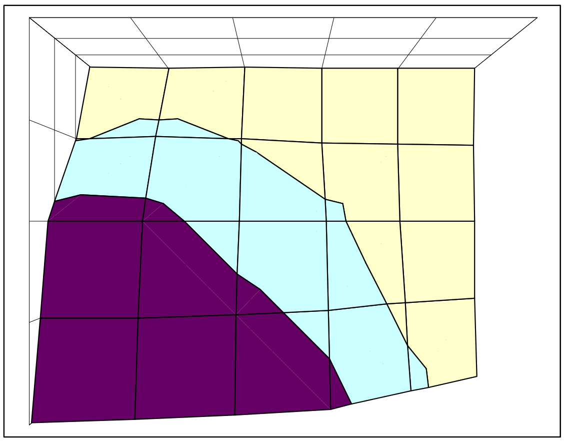


Fig. 3: Infrared thermographic photograph of the structure surface with the moisture map (see Fig. 2)

On the basis of the moisture determination by the contact moisture-meter, the moisture map of the discussed building structure detail was constructed, which is presented on the figure below.



Moisture: 3- 5 % 5 – 7 % 7 - 9 %

Fig. 4: The moisture map constructed on the basis of measurements with the contact moisture-meter (detail see fig.2)

The temperature map 3D was constructed following the infrared photograph of the temperature field distribution in the given detail of the structure. This map is on the picture below.

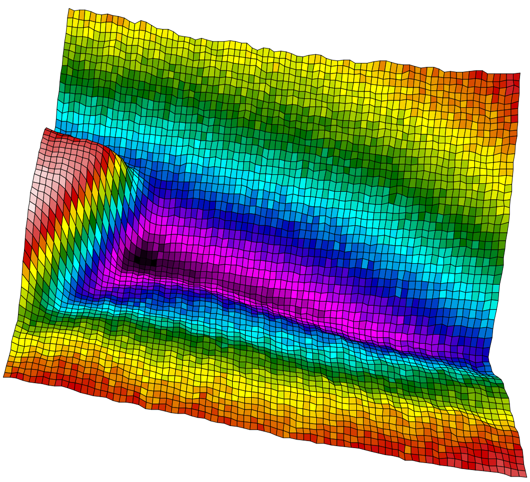


Fig. 5: The thermographic infrared 3D picture of the structure surface with the moisture- map (see Fig. 2)

It is obvious, following the figures 4. and 5, that the thermographic map reproduces the temperatures distribution in the moisture map. The correlation degree of the temperature and of the moisture map is given by the homogeneity of construction in concerned details.

CONCLUSION

It is obvious from the introduced case that the utilization of the infrared thermography is a very quick and effective method for the determination of moisture distribution in building structures. The main advantage of this method is the manifold quicker information about the moisture distribution on the surface of the structure in comparison with classical methods. This method can be used only as an additional one. It is always necessary to check the results of moisture determination pointwise by determination with classical methods (see above).

The main field of this method utilization is in primary diagnostics – the search of moisture failures reason. In this way it is possible, to monitor the moisture of the building structure at relatively great surface in relatively short time.

Further it concerns the area of the building structure moisture state longtime monitoring which is mostly realized in cases of moisture rehabilitation and rebuilding. We are in this cases interested in the borders of the moisture map which can be often detected visually only with difficulties, because during drying the crystallization of soluble salts takes place in the brickwork. These salts form on the surface colored spots, which can be in some cases misleading. The increased salinity of the brickwork surface makes very often impossible the utilization of some non-destructive methods for moisture determination.

The infrared thermography offers a relatively simple and quick method of the moisture determination in the building structure. The method is not applicable in all cases but its utility in the field of building structures failures diagnostic is very high and it can be expected that the utilization of this method will increase in the future.

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