Coupled heat and moisture transport in building material –
water absorption coefficient and capillary water content

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Abstract. At present, restoration of historic buildings is a difficult process. The most common problem of historic buildings is increased moisture, because waterproofing is missing and thanks that water can be transported in porous material by capillary forces. There is several simulation software available, which can include many factors such as water transport from the ground, sun radiation, impact of driven rain. Also it includes thermal conductivity, specific heat capacity and water vapor diffusion factor, which are depended on content of water. For correct assessment of hygrothermal behaviour of these buildings and find suitable retrofit strategies, hygric and thermal properties are needed. When we want to use simulation software for assessment of hygrothermal behaviour of historic structures, we need to know heat and water transmission parameters of sandstones. In this paper are presented two water transmission parameters and that water absorption coefficient and capillary water content. For the test measurement of these parameters was used clay brick. The water absorption and capillary water content are obtained by experiment of one-dimensional transport water. The results are compared with values of clay brick, which are presented in German material database.

1. Introduction
The moisture is one of the most common issue of existing buildings. It can affect not only service life and buildings energy efficiency but also their air quality in interior of buildings [1]. Water transport is crucial factor in terms of building design. When designing new buildings, civil engineers consider with transport water only as transport water vapor from the interior to the exterior. It is correct, because they can consider with waterproof insulations against ground water or waterproof plasters on the facades of buildings envelopes, but in historical buildings are usually missing and thanks that water can be transported to the porous materials of historical constructions. There is simulation software available, which can include influence of water to materials properties, sun radiation, driven rain, orientations of walls, wind and many others important factors. To use this software, it is necessary to know heat and water transmission parameters of historical materials [2]. In eastern Slovakia, sandstone was used in large quantities for construction of buildings. It was used for its compressive strength, good workability and aesthetic appearance. By the end of the 19th century, 336 quarries for sandstone mining were registered in the territory of eastern Slovakia [3]. Only a few scientists have studied the hygrothermal properties of sandstones. Transmission parameters of sandstones were studied by scientist in Canada [4], Czech Republic [5], and Germany [6] [7]. Capillary absorption coefficient (A_{\text{cap}}) and the capillary moisture content (w_{\text{cap}}) are important material properties. They can be determined by capillary absorption test, which is one of the most frequently performed material characterization test. There are many international and regional standards prescribing the procedures of the capillary absorption test [12], [13], [14], [15], but there are still some differences between procedures and rules. These differences include questions about sample size, area of bottom surface, sealing materials to providing one-dimensional transport water, temperature impact on A_{\text{cap}}, operational factors, weighing method. In this
paper, the test measurement is performed by using samples of clay brick with two different sealing materials.

2. Material information and sample preparation

2.1. Characterization of material
For test measurement was used common clay brick. It was chosen, because it has a typical tubular pore structure [8] and it is weak in hygroscopicity but strong in [9], this makes it suitable for capillary absorption test measurement.

2.2. Sample preparation
The size of the sample and the area of the bottom surface that is in contact with the water surface are one of the most disputable factors. The standard ISO 15148 requires, that a bottom surface area of sample should has minimum of 50 cm$^2$ for each sample [16]. The standard EN 1925 requires cubic sample with dimension 50, 70 mm or cylinder sample with diameter 50,70 mm and with height 50, 70 mm. Although there are several standards that set minimum dimensions of samples, many researchers often use much smaller samples with bottom surface areas ranging from 10 to 30 cm$^2$ [5], [9], [10], [11]. For test measurement were used cylindric samples with diameter 50 mm and height 60 mm figure 1. Two samples were made from one homogenous batch by core drilling machine and the bottom surface was treated by emery paper.

![Figure 1. Left: Preparation of cylindrical sample, Right: Cubic sample with diameter 50 mm.](image)

3. Experimental setup and measurement procedure

3.1. Principle of one-dimensional water transport experiment
By performing a water absorption test also called one dimensional water transport experiment, it is possible to determine the water absorption coefficient and capillary moisture content. The principle of this method is that the measured sample is immersed in the water and mass gain over time is monitored. The bottom surface of sample is in contact with water level to allow water absorption [16]. To providing only one-dimensional water transport, it is necessary to seal lateral sides and upper surface of the samples. The insulation must be perfect, because water can move in gap between sample and insulation material. Before the testing, samples must be dried at defined temperature 105°C [16] or 70°C [17]. After cooling down to temperature of the room in desiccator, oven-dried sample can be used for measurement. The test can be performed either with automatic or manual weighing. Some studies show
a good agreement between the results of manual and automatic weighing [10]. For this test was used apparatus with automatic weighing shown in figure 2. This apparatus was constructed according measuring device stated in [20]. It consists of a water container, a container lifter, a weighing machine, a rod for suspending sample, a data logger, which is connected to computer for monitoring temperature, relative humidity and weight gain.

3.2. Waterproof insulation
To reduce evaporation of water from the sample, it is necessary to insulate lateral sides of the sample. Insulation material must be vapor-proof and waterproof. Upper surface of the sample, must be vapor-proof but air-permeable, because of air leakage. In general, there are two sealing methods. Samples can be sealed by adhesive, non-adhesive film or by epoxy resin. According standard ASTM C1585 [18], both methods are acceptable. Bomberg et al. [10] stated that the self-adhesive tape should not be used, but without any theoretical explanations. Two different insulating materials were used for the test measurement, self-adhesive tape commonly used to insulate the gap between the walls and openings, and a heat shrink tube commonly used to insulate electrical cables. Both materials are shown in figure 3.

![Figure 2](image2.png)

**Figure 2.** Visualization of apparatus for one-dimensional water transport experiment (AWrora).

![Figure 3](image3.png)

**Figure 3.** Left: Sample with self-adhesive tape, Right: Sample with heat shrink tube.
Epoxy resin was not used, because it can be penetrated into the sample, what it can lead to reducing the effective cross-section size of the sample [9].

4. Determining of water absorption coefficient and capillary moisture content
One-dimensional water transport experiment can be divided into two stages. The first stage is characterized by a linear mass gain as a function of square root of time. During this stage, water absorption is governed by capillary forces. Water absorption coefficient $A_{cap}$ is defined as the slope of the cumulative water inflow versus square root of time in the first stage of the test figure 4. Second stage is characterized by non-linear mass gain and mass gain is slower. This stage takes a several days or months [19].

![Figure 4. Dependence of the weight gain of water on the square root of time.](image)

Water absorption coefficient $A_{cap}$ can be determined by using following equation (1) [19]:

$$A_{cap} = \frac{m_{wet} - m_{dry}}{t^{1/2}}$$

where $A_{cap}$ is water absorption coefficient $(kg/m^2.s^{1/2})$, $m_{wet}$ weight of the wet sample $(kg/m^2)$ per unit area $S (m^2)$, $m_{dry}$ is weight of the dry sample $(kg/m^2)$ per unit area $S (m^2)$, $t$ is time of experiment. Capillary moisture content $w_{cap}$ is defined as the moisture content at the transition from the 1st to the 2nd stage. More specifically, it is the moisture content, which correspond to the cross point with the fitting of the 1st and 2nd stages, as it is illustrated in figure 4. The capillary moisture content $w_{cap}$ can be determined by using following equation (2) [10]:

$$w_{cap} = \frac{m_{wet} - m_{dry}}{S \cdot H}$$

where $w_{cap}$ is capillary moisture content $(kg/m^3)$, $m_{wet}$ is weight of the wet sample $(kg/m^2)$ per unit area $S (m^2)$, $m_{dry}$ is weight of the dry sample $(kg/m^2)$ per unit area $S (m^2)$, $S$ is the area of the bottom surface $(m^2)$, $H$ is the height of the measured sample $(m)$.

5. Results and conclusion
The resulting water absorption courses in the experiment with two different sealing materials are presented in figure 5 and figure 6. Weight gain recording was performed by automatic weighing at defined times. The weight gain of clay brick with self-adhesive tape is shown in figure 5. The linear course of weight gain is not entirely perfect. It is not because the sample was lifted during the experiment. In figure 6 is shown weight gain of the clay brick with heat shrink tube. The linear course of weight is much better. Such a course is typical of an ordinary clay brick. The measurement results were compared with the different bricks Wienerberger 1, 2, ZD, ZE and Hartman from the German material database called MASEA [21]. They have different values of bulk density. In table 1, the best
match can be observed between values of $A_{cap}$ and $w_{cap}$ of brick Wienerberger 1 and values of measured brick with heat shrink tube. But on the other side, there is a bigger difference between values of bulk density. In the case of measurement with self-adhesive tape, the good match can be observed between $A_{cap}$ of brick ZD and measured brick. Also there is a small difference between values of bulk density. The measurement and comparison of the results indicates that there are significant differences between measurements with different sealing material and therefore further measurements are required.

![Weight gain - clay brick with self-adhesive tape](image1)

**Figure 5.** Weight gain during 1D experiment, clay brick with self-adhesive tape.

![Weight gain- clay brick with heat shrink tube](image2)

**Figure 6.** Weight gain during 1D experiment, clay brick with heat shrink tube.
Table 1. Comparison – measured brick and brick from German database MASEA [20].

| Material                        | Bulk density $\rho$ (kg/m$^3$) | Water absorption coefficient $A_{\text{cap}}$ (kg/(m$^2$.s$^{1/2}$)) | Capillary water content $w_{\text{cap}}$ (kg/m$^3$) |
|--------------------------------|---------------------------------|---------------------------------------------------------------|-----------------------------------------------|
| Measured brick – self-adhesive tape | 1567                            | 10.96                                                          | 265.32                                        |
| Measured brick – heat shrink tube  | 1579                            | 17.64                                                          | 286.45                                        |
| Brick - Wienerberger 1            | 1744                            | 17.5                                                           | 287                                           |
| Brick - Wienerberger 2            | 1786                            | 11.9                                                           | 262                                           |
| Brick – ZD                        | 1611                            | 10.9                                                           | 216                                           |
| Brick – ZE                        | 1642                            | 12.9                                                           | 254                                           |
| Brick – Hartmann                  | 1655                            | 14.4                                                           | 228                                           |

6. References

[1] Huijbregts Z, Schellen H, van Schijndel J, Ankersmit B 2015 Modelling of heat and moisture induced strain to assess the impact of present and historical indoor climate conditions on mechanical degradation of a wooden cabinet _Journal of Cultural Heritage_ 16 419-427

[2] Roels S, Carmeliet J, Hens H, Adan O, Brocken H, Cerny R et al. 2004 Interlaboratory Comparison of Hygroscopic Properties of Porous Building Materials _Journal of Thermal Envelope and Building Science_ 27 307-325

[3] Čabalová D 2013 Krása kameňa v životě človeka (Bratislava: Veda) 374

[4] Mukhopadhyaya P, Kumaran M K, Lackey J, Normadin N, Tariku F and van Reenen D 2007 Hygrothermal properties of exterior claddings, sheathing boards, membranes and insulation materials for building envelope design

[5] Kočí V, Maděra J, Fürst J, Žumář J, Pavlíková M, Pavlík Z et al. 2014 Service Life Assessment of Historical Building Envelopes Constructed Using Different Types of Sandstone: A Computational Analysis Based on Experimental Input Data _The Scientific World Journal_ 1-12

[6] Zhao J, Plagge R 2015 Characterization of hygrothermal properties of sandstones—Impact of anisotropy on their thermal and moisture behaviors _Energy and Buildings_ 107 479-494

[7] Krus, M 1996 Moisture transport and storage coefficients of porous mineral building materials: Theoretical Principles and New Test Methods (Fraunhofer IRB Verlag: Stuttgart)

[8] Roels S, Carmeliet J, Hens H, Adan O, Brocken H, Cerny R et al. 2004 Interlaboratory Comparison of Hygroscopic Properties of Porous Building Materials _Journal of Thermal Envelope and Building Science_ 27 307-325

[9] Feng C, Janssen H 2018 Hygric properties of porous building materials (III): Impact factors and data processing methods of the capillary absorption test _Building and Environment_ 134 21-34

[10] Bomberg M, Pazera M, Plagge R 2005 Analysis of Selected Water Absorption Coefficient Measurements _Journal of Thermal Envelope and Building Science_ 28 227-243

[11] Hanžič L, Kopec L, Anžel I 2010 Capillary absorption in concrete and the Lucas–Washburn equation. _Cement and Concrete Composites_ 32 84-91

[12] BS EN 1925, Natural Stone Test Methods. Determination of Water Absorption Coefficient by Capillarity (1999) 1999

[13] UNI 10859, Cultural Heritage – Natural and Artificial Stones – Determination of Water Absorption by Capillarity (2000) 2000.

[14] BS EN 1015-1018, Methods of Test for Mortar for Masonry. Determination of Water Absorption Coefficient Due to Capillary Action of Hardened Mortar (2002) 2002.

[15] UNI EN 15801, Conservation of Cultural Property – Test Methods – Determination of Water Absorption by Capillarity (2010) 2010

[16] ISO 15148:2002(E), Hygrothermal Performance of Building Materials and Products – determination of Water Absorption Coefficient by Partial Immersion (2002)

[17] STN EN 1925: 2002. Skúšky prirodného kameňa. Stanovenie súčiniteľa nasiakavosti kapilaritou

[18] ASTM C1585-13: 2013. Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-cement Concretes
[19] Vertaľ M and Ďurica P (2013) Prenosové parametre vody vo vybraných stavebných materiáloch (Košice: Technická univerzita v Košiciach, Stavebná Fakulta) 98

[20] Plagge R, Scheffler G and Grunewald J 2005 Automatic Measurement of Water Uptake Coefficient of Building Materials Bauphysik 27 315–323

(online): https://www.masea-ensan.de/

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