Measuring of the moisture content in brick walls of historical buildings – the overview of methods

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Abstract. The paper deals with the issue of measuring the moisture content of brick walls in buildings of high historical value. It includes a classification of known methods used to measure the moisture content and their valorisation with regards to the legitimacy of using them in historical buildings. Moreover, the most important considerations for conducting such measurements are also described, which include the choice of an appropriate method for a specific situation, the determination of a correlative or hypothetical dependency for equipment used in tests and also the method of distributing measurement points.

1. Introduction

The problem of the excessive moisture content of brick walls in historical objects is present in many European countries because of their rich cultural heritage and dense accumulation of historical buildings. The consequence of long-term moisture, usually combined with excessive salinity, is the severe and extensive destruction of wall components (Fig. 1). At the beginning of the renovation works of such objects, specialized tests of the moisture content should be first executed. If the moisture content in walls exceeds the permissible level [1, 2], it is necessary to undertake measures for its reduction (Fig. 2).

Figure 1. An exemplary view of damp brick walls in a building.
Performing tests of the moisture content in the walls of historical buildings does not usually turn out to be an easy task. This is because monument protection authorities only allow intervening in the structure of the historic tissue to a very limited degree. This restriction excludes the free use of destructive methods, which are based on taking samples of walls for testing. Therefore, non-destructive methods should also be used. In case of a monument it is important to draw up and agree with the conservator the scope of the research prior to the commencement of the moisture measurements.

There are many non-destructive methods of measuring moisture content described in literature, however, it should be noted that various methods have some restrictions in usage and that there are general conditions for the performance of non-destructive testing of moisture content. It is fundamental to obtain reliable test results, which can subsequently lead to knowledge of the distribution of moisture around the perimeter of walls and along their height as well as the causes of moisture. Moreover, it can lead to a decision about natural or accelerated drying of walls, which can be the basis for calculating the cost of drying.

Taking the above into consideration, the paper presents the classification of the methods that are useful for moisture testing whilst indicating those that are predisposed to be used in historical buildings. On the basis of the experience gained during the conducting of tests on historical buildings, for instance [11, 12, 13], the most important conditions for conducting these types of tests in relation to the selection of an appropriate test method for the specific situation were also described.

2. Overview of methods for testing the moisture content with regards to the possibility of being used in historical buildings

Methods of testing the moisture content of brick walls can generally be divided into two main groups: destructive methods that require the taking of material samples for testing, and non-destructive methods that do not require intervention in the structure of the object [3]. Furthermore, various methods are known as either direct or indirect, depending on whether just the moisture content is measured or if a different physical or chemical characteristic of a wet material, the value of which is affected by the water content, is tested. Own classification of all destructive and non-destructive, as well as direct and indirect methods for measuring the moisture content of brick walls is provided in Figure 3.
Figure 3. Classification of methods for testing the moisture content of brick walls.

The destructive direct gravimetric method gives the most reliable results out of all known methods when measuring the moisture content in brick walls. It enables the value of the moisture content on the surface and along the thickness of the tested partition to be determined. However, it is necessary to take and test in-situ material samples during the use of this method. Therefore, it cannot be freely used in historical buildings.

Taking samples for testing is also required when using the other two destructive indirect methods: carbide and chemical (Karl Fisher). Measurements made with the carbide method give worse results in comparison with the gravimetric method [1, 3]. In turn, the chemical method is based on the use of very small samples, and for this reason it is unreliable and rarely used in construction practice [4].

In the case of the last destructive indirect method included in Figure 3 - the electrical resistivity method - intervention in the wall structure consists of drilling a number of holes of small diameter, in which electrode needle probes are placed. The method of conducting tests is therefore quite problematic and almost impossible to be carried out on historic buildings.

In the case of non-destructive methods, their undoubted advantage is the fact that there is no interference in the structure of a wall and there is therefore an opportunity to conduct research in any number of measuring points. However, out of the many non-destructive methods for the testing of the moisture content in brick walls that have been described in literature, only a few of them allow the moisture content and its distribution in a wall to be reliably assessed [5, 6].

In the case of non-destructive methods, the evaluation of the moisture content is only qualitative and not quantitative. This refers to the chemical method of paper indicators, where the moisture content level is determined on the basis of the change in colour of indicator papers after their contact with the surface of the moist material.

The same thing applies in the case of methods that are based on the measurement of thermal properties. These methods are: infrared, optical, and videography. For example, the infrared method is characterized by a high availability of equipment and it enables the thermal radiation emitted by the tested partition, in the form of a surface thermogram of the tested element, to be registered with the use of an infrared camera [7]. This method is very useful for locating damp areas in a wall but there is no possibility to determine the value of the moisture content.

In turn, methods of scanning with γ radiation, such as the neutron method and the nuclear magnetic resonance method, are based on interaction between nuclear radiation and a tested element.
Measurements with the use of these methods are non-contact and precise, but due to the limited availability of equipment and high cost of tests, they are not used in the in situ testing of moisture content.

The method of electrical impedance tomography has been developed relatively recently. It aims to enable a picture of the spatial distribution of the mass moisture content in a wall to be obtained. The operation and applicability of this method has until now only been confirmed in laboratory studies [4]. However, it has not yet been applied in practice due to a lack of available equipment.

The dielectric and microwave methods are the most often used for in situ testing of the moisture content in brick walls. This is due to the availability of equipment and ease of use. The dielectric method allows the moisture of a partition in the surface zone and to a depth of about 50 mm to be measured, while the microwave method allows the measurement of the moisture content in the deeper parts of a wall i.e. to a depth of about 300 mm to be conducted. This maximum depth of penetration significantly reduces when the surface area of the wall is more damp than the deeper parts. It should also be noted that the moisture value obtained by this method should be regarded as averaged from the depth of 0 to 300 mm.

Due to the conducted analysis and in order to locate the damp areas of a wall in historical buildings, it is highly recommended to use the infrared method. In turn, to identify the values of moisture content, the most currently predisposed methods are the dielectric and microwave methods.

3. The guidelines of conducting the measurements
Before the start of non-destructive testing of the moisture content in a brick wall and to reliably assess its value and distribution, an appropriate research method should first be chosen. These tests should be preceded by performing tests using the destructive gravimetric method but to such an extent to which monumental protection authorities allow and which will enable the correlative or hypothetical dependencies between the non-dimensional parameter $X$ and the mass moisture content $U_m$ to be determined (Fig. 4). Moreover, the moisture distribution along the thickness of at least one inner and one outer wall must also be specified (Fig. 5). It should be clarified that in the dielectric method the phenomenon of change of the dielectric constant due to dampness is used, whereas in the microwave method the attenuation of the microwaves passing through the damp material is measured. In both cases, the result of the measurement is the dimensionless number (parameter $X$).

![Methods of determining the dependency $U_m - X$](image)

**Figure 4.** Methods of determining the dependency $U_m - X$ for the non-destructive dielectric or microwave method that was used in tests, based on [14].

The moisture distribution along the thickness of a wall that was obtained using destructive testing determines the choice of the non-destructive measuring method. In the surface zone, the moisture generally remains at a lower level than in the deeper parts of a wall. The difference of these levels ($\Delta U_m$) depends on the conditions in the close vicinity of a damp partition and this determines the speed of drying the moisture from a wall. In the case when the values of the moisture are similar throughout the thickness of the whole partition, therefore when they do not differ by more than 3%, the test can be
successfully carried out using the dielectric method. Otherwise, it is advisable to use the microwave method, which allows measurements of the moisture content of up to a depth of 300 mm to be carried out.

Figure 5. Possible mass moisture content distributions along the thickness of a wall: a) in an interior wall – the case, when the air moisture and temperature from both sides of the wall are the same; b) in an outer wall.

In order for the results that were obtained with the non-destructive methods to be reliable, samples should also be tested for their salinity. Water-soluble salts, which have the largest concentration in the surface zone of a wall, have a significant influence on the results that are shown on the apparatus used in measurements. For this reason, it is important that the selection of a hypothetical relation $U_m - X$ was made only from relations specified on real objects rather than in a laboratory. It is worth mentioning that the existing research shows that salinity has a significant impact on results obtained by the dielectric method causing the moisture content to be overestimated relative to the real humidity, while in case of the microwave method the impact of the salt content in masonry on the measuring results is insignificant [8, 15].

As was previously mentioned, the non-destructive methods provide an opportunity to conduct research in any number of measuring points. It is therefore very important to locate them in order to get the moisture profiles of a tested partition along its height (Fig. 6), the length of a wall, along the perimeter of walls and also at different levels, as shown in Figure 7.

Figure 6. Exemplary mass moisture profiles $U_m$ along the height of walls.
In the case of walls with a considerable thickness, it is advised to perform moisture profiles on both sides of the wall. They are not only very useful to determine the causes of moisture in a wall, but also to estimate how fast the process of their natural drying will be. This provides the basis of whether to increase the intensity of drying using various types of equipment and also whether to calculate the costs of such accelerated drying.

![Exemplary mass moisture profiles](image)

**Figure 7.** Exemplary mass moisture profiles $U_{m}$ that were obtained along the circumference of outer walls at three levels above the floor.
4. Summary
Non-destructive methods are predisposed to carry out measurements of the moisture content in brick walls of historical buildings because the free use of destructive methods is not accepted by the monumental protection authorities. In this paper, the classification of these methods was presented and a few that are currently best suited to be used in these types of objects were indicated. These are the microwave method and the dielectric method, which are included in the group of electrical methods. When carrying out measurements using non-destructive methods, some determinants should be taken into account. This guarantees a reliable and complete picture of the moisture content to be obtained. It is necessary, among others, to choose an appropriate measuring method for the specific situation, specify a correlative or hypothetical dependency between the non-dimensional parameter $X$ and the mass moisture content of a wall $U_m$ and also to properly arrange the measuring points to obtain moisture profiles at the height of a wall, along its length and also at the circumference of walls at their different heights above the floor.

Knowledge of the above-mentioned profiles, which is currently undervalued, is of particular importance. It allows the causes of excessive moisture to be determined, the amount of moisture in a wall to be estimated, the progress of natural drying to be assessed, whether accelerated drying is required and also its costs to be determined.

References
[1] Adamowski J, Hola J and Matkowski Z 2005 Probleme und Losungen beim Feuchtigkeitsschutz des Mauerwerks von Baudenkmalern am Beispiel zweier grosser Barockbauten in Wroclaw Bautechnik vol 82, issue 7 pp 426-33
[2] Rokiel M 2006 Hydroinsulations in Civil Engineering (Warsaw: Medium Publishing House)
[3] Jasieńko J and Matkowski Z 2003 Salinity and the moisture content in brick walls of historic buildings - diagnosis, research methodology, techniques of rehabilitation, Wiadomości Konserwatorskie vol 14, pp 43-8
[4] Hola J, Matkowski Z, Schabowicz K, Sikora J, Nita K and Wójtowicz S 2012 Identification of moisture content in brick walls by means of impedance tomography Compel vol 31 pp 1774-92
[5] Adamowski J, Hola J and Matkowski Z 2007 Drying and renovation of flooded buildings Naprawy i Wzmocnienia Konstrukcji Budowlanych vol 2 (Bielsko-Biała: PZITB) pp 5-43.
[6] Karyś J et al. 2001 Protecting buildings against biological corrosion ed J Ważny and J Karyś (Warsaw: Arkady)
[7] Nowak H 2012 The application of infrared testing in Civil Engineering (Wrocław: Wrocław University of Science and Technology Publishing House)
[8] Pala A 2013 The influence of salinity on ceramic brick moisture content test results obtained using the nondestructive dielectric method International Interdisciplinary PhD Workshop 2013 (Brno: Brno University of Technology) pp 156-60
[9] WTA 2-6-99-D, Erganzungen zum Merkblatt 2-2-91-D Sanierputzsysteme
[10] CSN P 73 0610: Waterproofing of buildings – The rehabilitation of damp masonry and additional protection of buildings against ground moisture and against atmospheric water – The basic provision (2000)
[11] Hola A, Matkowski Z 2014 Nondestructive testing of damp vault brickwork in a gothic-renaissance city hall XIth European Conference on NDT 2014 (Brno: Brno University of Technology) pp 1-7
[12] Hola A, Matkowski Z and Hola J 2017 Analysis of the moisture content of masonry walls in historical buildings using the basement of a medieval town hall as an example Procedia Engineering vol 172 pp 363-68
[13] Hola A 2015 Tests of the damp timber-framed construction of a historic church building International Review of Civil Engineering vol 6 pp 39-42
[14] Zięba A 2013 Data analysis in science and technology (Warsaw: PWN Scientific Publishing
Goetzke-Pala A, Hola J 2016 Influence of burnt clay brick salinity on moisture content evaluated by non-destructive electric methods *Archives of Civil and Mechanical Engineering* vol 16 pp 101-11