Open Access
Original paper

Budownictwo i Architektura – Civil and Architectural Engineering 24(4) (2025) 25014
https://doi.org/10.35784/bud-arch.8768

Moisture investigations in heritage structures – the influence of masonry salt content on the reliability of dielectric measurements

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Received: 19.11.2025; Revised: 17.12.2025; Accepted: 18.12.2025; Available online: 19.12.2025

Abstract:
Excessive moisture is one of the most common problems in heritage monumental buildings. This phenomenon is mainly due to the lack of original waterproofing in most buildings and the frequent failure of solutions implemented in later periods. As a result, moisture content measurements are among the most frequently performed diagnostic tests in this type of building. The greatest difficulty remains in the destructive nature of laboratory tests. In the case of the gravimetric method, it is necessary to collect material for testing, which results in the need to interfere with valuable historic substances. For this reason, conservation authorities are reluctant to grant permission for sampling, and even when permission is granted, the number of permissible measurement points is often significantly limited. For the above reasons, indirect, non-destructive methods are commonly used in diagnostic practice. The most common technique is the dielectric method, which does not require interference with the structure of the material being tested. However, it should be emphasised that the presence of salt in the material changes its dielectric properties, which can lead to significant measurement errors. The aim of this article is to determine whether and to what extent the salt content affects the reliability of moisture measurements performed using indirect methods.

Keywords:
brick masonry dampness, masonry salt content, dielectric method, gravimetric method, heritage monumental

1. Introduction

Excessive moisture is one of the most common problems in historic buildings, and its impact on the rate of degradation of historic masonry is well documented in the literature [1,2]. This phenomenon results primarily from the absence of original waterproofing systems and from the frequent failure of secondary solutions, often introduced during later modernisation phases [3]. Consequently, ground moisture, rainwater and construction moisture may penetrate deep into the building envelope, leading to a range of destructive processes [4], such as material corrosion, fungal growth, salt crystallisation and the deterioration of the thermal and mechanical properties of masonry.

In buildings, particularly historic ones, moisture in masonry walls is a common phenomenon and affects not only the walls themselves but also adjacent structural and finishing elements. This concerns in particular timber components, which often form parts of floor structures, roof trusses or interior claddings. Studies have shown that fluctuating moisture content can significantly modify the thermal properties of such materials, and this effect is amplified under conditions of elevated relative humidity, which influences the energy demand and thermal comfort of indoor spaces [5]. At the same time, the use of moisture-regulating plasters can stabilise microclimatic conditions indoors and reduce the risk of water vapour condensation [6], whereas in the case of modern materials such as GFRP boards, the presence of moisture leads to measurable changes in physical properties, which can be effectively monitored using non-destructive techniques [7].

Due to the scale of this phenomenon, moisture measurements are among the most frequently performed diagnostic tests in historic buildings [3]. The most reliable method for determining the mass moisture content of building materials is the gravimetric (oven-drying) method, specified in standard PN-EN ISO 12570 [8]. It provides high accuracy and repeatability of results; however, its application in conservation practice is limited, as it requires sampling from the masonry, which entails interference with the valuable historic fabric [2,3]. Sampling for laboratory testing requires substantial intrusion into the masonry structure. Regardless of the sampling technique applied (whether core drilling, chiselling, or the collection of drilling dust) the finishing layers are inevitably damaged. These layers often constitute protected elements of the historic fabric, including claddings, renders, paint layers, and architectural details. This issue is of lesser significance in basement areas. However, it becomes particularly critical in the case of façades and rooms located on above-ground storeys. Moreover, the investigations conducted frequently require a large number of measurements, which significantly increases the extent of material damage. Consequently, heritage conservation authorities are often reluctant to grant permission for material sampling, and the number of permissible test locations remains strictly limited.

In view of the above limitations, the diagnostics of historic buildings increasingly rely on indirect, non-destructive or quasi non-destructive methods, such as electrical techniques – including the resistance method and the dielectric method. The dielectric method, in particular, has gained wide popularity, as it enables rapid, point-based measurements and the development of moisture distribution maps within building envelopes. Its main advantage is that it does not require any intervention in the material, which makes it a commonly used tool for assessing the condition of historic masonry.

However, the dielectric method is subject to several limitations. The first concerns the relatively shallow measurement depth. Most measuring devices are capable of assessing moisture content only within the outermost layer, typically to a depth of several tens of millimetres. As a result, the measurements reflect solely near-surface conditions, most commonly within the render layer or the exposed face of unrendered masonry, while providing no information on the moisture state within the core of the wall. Furthermore, due to the design of the measuring probes, many devices require relatively smooth and even surfaces, which hinders accurate measurements on irregular substrates, such as brick masonry with damaged faces or stone walls composed of unworked elements. The most significant limitation, however, is the influence of salt content on measurement reliability. In heritage structures, dielectric moisture measurements are often severely distorted by the presence of soluble construction salts. Salt contamination is a common phenomenon in historic masonry, as confirmed by numerous field studies [2,9]. Salts such as sulphates, chlorides and nitrates migrate with moisture into the material structure and subsequently crystallise in evaporation zones, generating crystallisation pressures that exceed the local strength of bricks and mortars [2,10]. This phenomenon leads both to the destruction of surfaces and joints and to changes in the physical properties of materials, including their response to electric fields.

Laboratory investigations and theoretical analyses clearly indicate that salt solutions increase the ionic conductivity of porous materials and therefore significantly affect moisture measurements performed using electrical methods. Hall and Hoff [11] confirmed that electrical conductivity increases with ion concentration in the pores, which leads to overestimation of readings obtained from dielectric sensors. Lubelli and van Hees demonstrated that even moderate concentrations of sulphates and nitrates may cause false electrical moisture readings, irrespective of the actual water content [12]. Field studies carried out by the Authors of the present paper, Szostak and Trochonowicz, showed that in highly salt-contaminated masonry, the zones with the highest salt concentrations coincided with the zones of the highest dielectric moisture readings, despite the absence of a proportional increase in the actual moisture content [9]. The publication highlights that misinterpreting salt contamination as moisture is particularly hazardous, as it may result in inadequate design decisions, such as the selection of unsuitable drying systems or renovation plaster systems.

RILEM [13] and the WTA guidelines [14] recommend, in such cases, combining different measurement techniques with chemical analysis of salts and laboratory testing of the material.

The influence of salt contamination on the reliability of indirect measurement methods was the subject of studies conducted by researchers from Wrocław University of Science and Technology. In 2013, two articles were published on the investigation of salt-contaminated ceramic brick using non-destructive dielectric and resistance methods [15,16]. In both cases, the conclusions were similar: it was clearly demonstrated that salt loading has a significant effect on the results obtained with electrical meters (dielectric and resistance).

The publication concerning investigations using the dielectric method proved to be particularly significant. In the experimental programme, three different salt environments (nitrate, chloride and sulfate) were used to achieve the initial salt contamination. Subsequent tests showed that the type of salt had no major influence on the final results, whereas the dominant factors affecting the measurement error were the concentration of the solution and the salt content in the brick. The most important conclusion of the study is the necessity of site-specific calibration of dielectric meters in a given building in order to establish the relationship between the instrument readings and the actual moisture content of the material.

Dielectric (indirect) moisture measurements, due to their numerous limitations and often unsatisfactory accuracy, should not be regarded as fully reliable. In practice, they are most commonly used for preliminary assessment of the moisture condition. The rapid measurement procedure and the absence of any intrusion into the structure of the building make it possible to perform a very large number of measurements. Even in the case of large buildings, areas suspected of high moisture content can be identified quickly, which facilitates the planning of laboratory moisture tests. In addition, the results obtained with the dielectric method allow moisture maps to be generated on wall and floor surfaces.

Investigations are conducted using the dielectric method. Measurements are typically performed along vertical profiles, most commonly at five or six height levels spaced at intervals of approximately 0.5 m. The horizontal spacing between measurement axes depends on the size of the investigated structure (façade or wall) and usually ranges between 0.5 and 1.0 m. The collected data are processed in tabular form, most commonly using spreadsheet software such as Excel. Subsequently, moisture distribution maps are generated using specialised software packages, including Surfer, MATLAB, Python-based tools, or CAD software equipped with interpolation plug-ins. The final output may take the form of a two-dimensional projection with a colour gradient or an iso-moisture contour map. The map in Fig. 1 shows the distribution of wall moisture in a historic manor house up to a height of 2.20 m. The darker the colour, the higher the moisture content in a given area; the exact moisture ranges are given in Table 1. The map in Fig. 3 shows the distribution of wall moisture in a historic tenement building up to a height of 2.40 m.

For both buildings (Fig. 1, Fig. 2), destructive laboratory (gravimetric) tests were also performed. In both cases, the dominant source of moisture was ground water drawn upwards by capillary action. Laboratory tests with samples taken at three heights (0.10 m, 0.60 m, and 1.20 m) showed a consistent decrease in moisture content with increasing height. In the graphical representations based on dielectric measurements, an irregular moisture distribution is visible. In the maps (Fig. 1 and Fig. 3), zones in the upper wall sections appear with theoretically higher moisture contents than in the areas below. In most of these zones, damage typical of salt crystallisation was observed. The presence of large amounts of crystallised salts had an adverse effect on the reliability of the measurements.

Taking the presented results into account, a key question arises as to the extent and degree to which salt content affects the reliability of moisture measurements performed using the dielectric method, and whether this method can be applied independently in the diagnostics of building envelopes with a significant level of salt contamination. The aim of the present paper is to assess the scale of this phenomenon and to analyse the applicability of the dielectric method in investigations of historic masonry, in which salt contamination is a common occurrence.

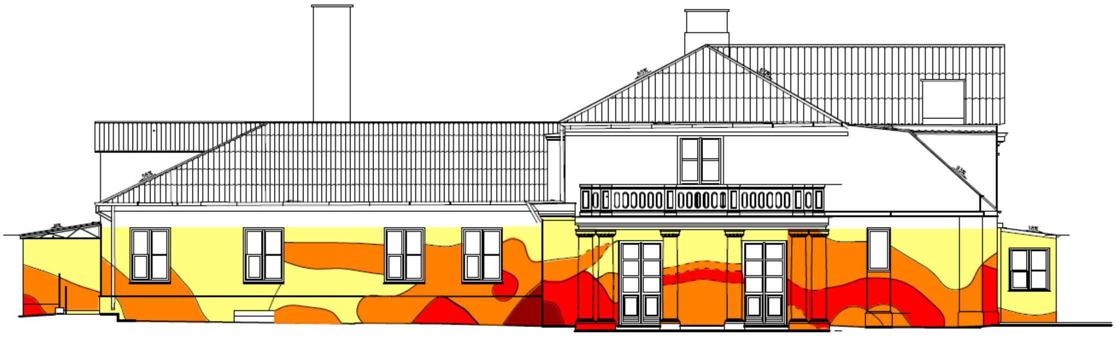

Fig. 1. Moisture maps were prepared for a historic residential manor house located in Brzezice, Lublin Voivodeship, Poland. Source: own study

Table 1. Degrees of moisture content in brick masonry. Source: [17]

Degrees of moisture content in brick masonry		
I	0-3%	Masonry with acceptable moisture content
II	3-5%	Masonry with elevated moisture content
III	5-8%	Moderately damp masonry
IV	8-12%	Highly damp masonry
V	>12%	Wet masonry

Fig. 2. View of the elevation of a tenement house located on Peowiaków Street in Lublin, Poland. Source: own study

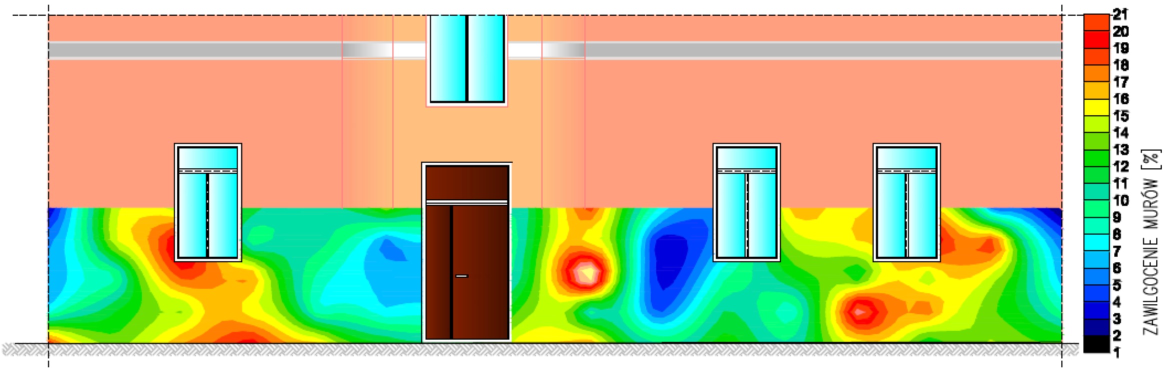

Fig. 3. Moisture map prepared for the ground-floor zone of a tenement house located on Peowiaków Street in Lublin, Poland. Source: own study

The degree of masonry salt contamination is the amount of salts determined in laboratory tests, expressed as a percentage relative to the mass of the material. This test makes it possible to classify the loading with harmful salts and provides a basis for planning remedial measures. By determining the degree of salt contamination, it is possible to design the configuration and thickness of the layers in renovation plaster systems, which are applied to counteract the destructive action of salts in masonry. In most cases, chloride, nitrate and sulfate ions are determined. In the literature, threshold values are given either in [%] or in [mmol of salt/kg of material]. The degrees of salt contamination are reported for individual salts or collectively. One proposal for defining the degree of salt contamination was put forward by Frössel. In his publication [18], he presented a five-level classification (Table 2) with salt content expressed in [mmol of salt/kg of material], together with a description of the consequences of salt loading in masonry.

Table 2. Salt loading levels. Source: [18]

Level	Salt content [mmol of salt/kg of material]	
I	0-2.5	The wall structure contains only trace amounts of salts; the formation of visible damage can therefore be excluded.
II	2.5-8	There is a low salt loading of the wall structure. The development of visible damage is only possible under favourable conditions.
III	8-25	There is a moderate salt loading of the wall structure. In accordance with the solubility and hygroscopicity of the salts, water is absorbed and stored within the building material. As a result, the functions of plasters and paint coatings are reduced.
IV	25-80	There is a high salt loading. The functions of plasters and paint coatings are significantly reduced. Complete drying of the wall is not possible, even when horizontal or vertical damp-proofing is installed. There is a high probability that wet areas will appear on the walls.
V	>80	This represents an extreme salt loading. Damage and hygroscopic dampness may reoccur within a short period of time.

According to the Austrian standard ÖNORM B 3355 [19], three salt contamination groups are distinguished (Table 3). In the case of Group I, no preventive or remedial measures for the building materials are required. At the second level of salt contamination, remedial actions are necessary only in selected cases. By contrast, when the salt contamination in the investigated structure corresponds to Group III, remedial measures should be implemented as a matter of urgency.

Table 3. Classification of salt contamination level. Source: Ö-Norm B 3355 „Drying of damp masonry – Building diagnosis and planning principles" [19]

Anions	Salt content [% by mass]		
	I	II	III
Chloride	< 0.03	0.03-0.10	> 0.10
Nitrate	< 0.05	0.05-0.15	> 0.15
Sulphate	< 0.10	0.10-0.25	> 0.25

WTA [14], the German Scientific and Technical Working Group for the Preservation of Historic Buildings and Monuments, which is concerned with the conservation and maintenance of heritage structures and historic building fabric, classifies salt contamination into three levels of salt loading: low, moderate and high (Table 4).

Table 4. Salt concentration level. Source: WTA 2-9-04/D „Remedial plaster systems" [14]

Salt	Mass content [%]		
Chlorides Cl^-	< 0.2	0.2-0.5	> 0.5
Nitrates NO_3^-	< 0.1	0.1-0.3	> 0.3
Sulphates SO_4^{2-}	< 0.5	0.5-1.5	> 1.5
Concentration level	low	moderate	high

Long-term research conducted by the authors of the present paper on 29 historic buildings, including tenement houses, sacral structures and manor–palace complexes, covered a total of 255 samples taken for laboratory determination of salt content. Analysis of the results (Fig. 4) showed that, in the case of sulphates, 48% of the samples were characterised by a medium concentration, 40% by a low concentration and 12% by a high concentration. For nitrates and chlorides, only 4% of the samples reached a high concentration level, while 11% of the samples exhibited a medium level of nitrates and 17% a medium level of chlorides. In both groups, samples with low salt concentrations predominated. The comparison of results indicated that only 25% of the samples could be classified as non-contaminated, which means that in the remaining 75% of cases the presence of salts may significantly affect the results of dielectric moisture measurements, potentially leading to their distortion.

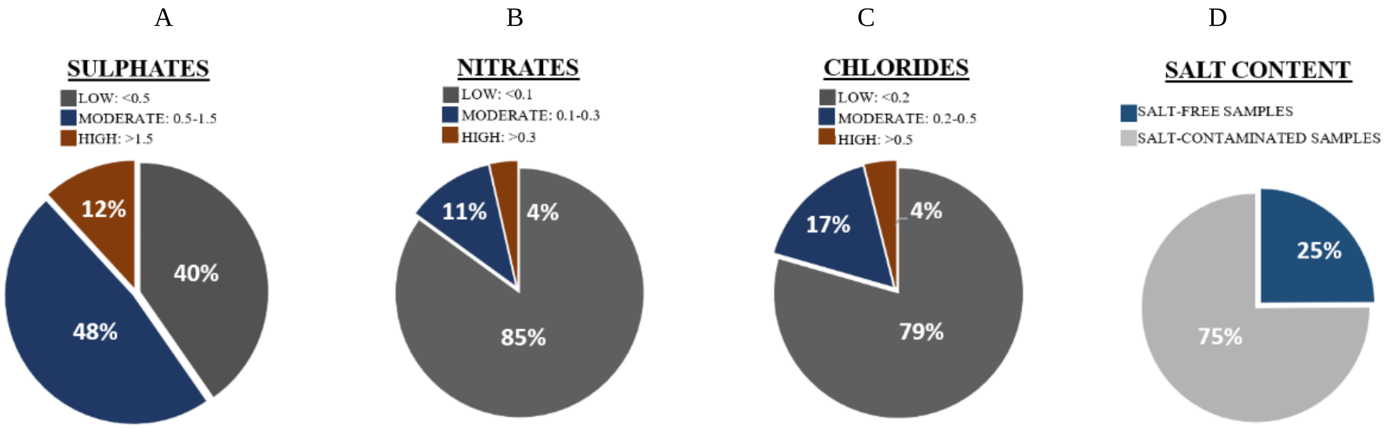

Fig. 4. Graphs showing the percentage content of sulphates (A), nitrates (B), chlorides (C) and the overall salt contamination level (D) in the tested samples. Source: own study

2. Materials

2.1. Solid ceramic brick

The tests were carried out on solid clay bricks, selected as the masonry material due to their widespread use in historic buildings. Bricks meeting the requirements of category HD and strength class 10 in accordance with PN-EN 771-1:2011 [20] were used. The material was characterised by good technical and functional performance. The mean normalised compressive strength determined perpendicular to the bed face was 10 MPa. The gross density of the units was determined to be 1780 kg/m^3. The nominal brick dimensions were 250 × 120 × 65 mm, and the unit mass was 3.8 kg.

During preparing the test specimens, a visual selection of the units was performed. Bricks with uniform colour and smooth, undamaged surfaces were selected for further analysis. Specimens exhibiting cracks, spalling, salt efflorescence or other surface defects were excluded.

2.2. Salt solution

In view of the fact that the type of salt has no major influence on the final results, whereas the dominant factors affecting the measurement error are the solution concentration and the salt content in the brick [16], sodium chloride was selected for the salt loading tests.

The salt solution was prepared by mixing tap water with table salt (NaCl). The amount of salt was determined according to the intended solution concentration. Based on the mass moisture content equation and the dry mass of the specimen, the required amount of salt solution to be added to each specimen was calculated in order to obtain the assumed moisture contents and salt concentrations in the range from 0.5% to 2.5%.

3. Methodology

Indirect methods for determining moisture content in masonry are based on measuring parameters related to the physical and chemical properties of water present in the material pores. The result is obtained from the relationship between these parameters and the measured quantity. A number of external factors may influence the outcome of indirect measurements; therefore, the obtained value cannot be regarded as fully reliable. The results obtained in this way should be treated as semi-quantitative and primarily informative in character.

3.1. Achieving the target moisture content and salt concentration

To achieve the desired material moisture content and the required salt concentration, the experimental procedure began with drying the specimens to constant mass, followed by their immersion in the salt solution. Drying was carried out in a climate chamber at a temperature of 100 °C ± 5 °C until the mass stabilised, confirming the complete removal of free water. The specimens were then weighed, and the required amount of solution was calculated using the mass moisture content equation, ensuring that, after immersion, the target moisture level was reached.

The tests were performed for six concentrations: 0% (specimens immersed in tap water), 0.5%, 1%, 1.5%, 2% and 2.5%. The specimens were saturated to obtain moisture contents in the range of approximately 2% to 15%. To prevent water evaporation, the specimens were wrapped in foil immediately after soaking. The bricks were then stored for 14 days at ambient temperature and regularly rotated to ensure a uniform distribution of water throughout the material.

3.2. Dielectric moisture measurement

Moisture measurements were carried out using the dielectric method with a LAB-EL LB 796 meter (Fig. 6). The procedure consisted in selecting the appropriate material type from the device menu, placing the measuring head on the specimen surface and gently pressing it (Fig. 5), and then reading the moisture value directly from the display. The results were recorded in prepared test sheets, with the laboratory measurements taken immediately after the specimens had been uncovered. The method is straightforward, quick to apply and provides information on moisture content from depths of the order of several tens of millimetres, which makes it useful for detecting zones of elevated moisture and for producing moisture distribution maps in building envelopes. However, it should be emphasised that the results are indicative only, and their values may be influenced, among other factors, by the material properties and its salt content.

Fig. 5. Moisture measurement using the dielectric method. Source: own study

Fig. 6. Measuring device LAB-EL LB 796. Source: own study

3.3. Laboratory (gravimetric) moisture measurement

Moisture measurements were performed using the gravimetric method in accordance with PN-EN ISO 12570 [8]. The gravimetric method consists in determining the moisture content of the material by measuring the difference in specimen mass before and after drying. The water contained in the specimen is removed during the drying process, and the mass loss corresponds to its moisture content.

Samples were taken after the indirect measurements had been completed. Under laboratory conditions, the mass in the moist state and the mass after drying at 105 °C to constant mass were determined. The procedure was as follows:

1. Preparation of the specimens.
2. Weighing of the collected specimens together with the container to an accuracy of 0.001 g using an Adventure Pro Type AV264CM balance.
3. Drying for 72 h at 105 °C until constant mass was achieved.
4. Weighing of the dried specimens.
5. Weighing of the empty containers to enable correct calculations.
6. Calculation of the moisture content in percent by mass using Eq. 1.

Mass moisture content was determined from the following equation:

$$W_m = \left[\left(m_w - m_s\right) / m_s\right] \cdot 100\% \qquad (1)$$

where: m_w – mass of the wet sample [g], m_s – mass of the dry sample [g].

3.4. Salt content analysis

The chloride content in the tested sample was determined using the Aquamerck® 111106 chloride test (MERCK) (Fig. 7). The analysis was based on an argentometric titration with diphenylcarbazone as the indicator. A reagent kit with a graduated pipette for titration was used. The scale on the pipette was graduated in steps of 2 mg/L [21].

The nitrate content in the tested sample was determined using a colorimetric method based on the Aquamerck® nitrate test (MERCK) (Fig. 8). In this method, nitrates are treated with a reducing mixture and converted to nitrites, which react with sulfanilic acid in an acidic solution to form a diazonium salt. The salt then couples with a benzoic acid derivative, resulting in the formation of an azo dye with an orange-red colour. The nitrate concentration was measured semi-quantitatively by visually comparing the colour of the test solution with the colour zones on the reference chart supplied with the kit [22].

The Aquaquant® test used for sulfate determination is a semi-quantitative colorimetric method based on the reaction of sulphates with a specific dye reagent (Fig. 9). After adding the water sample to a cuvette or test tube containing the reagents, a precipitate formed and a colour change occurred, the intensity of which corresponded to the concentration of sulfate ions (SO_4^{2-}). The colour of the sample was then compared with the colour scale supplied with the kit, which made it possible to determine the sulfate concentration range [23].

Fig. 7. Chloride test Aquamerck® 111106. Source: own study

Fig. 8. Nitrate test Aquamerck® 111170. Source: own study

Fig. 9. Sulphate test Aquaquant® 14411. Source: own study

4. Results

Moisture measurements were carried out on 6 independent specimens for each combination of solution concentration and substrate moisture range, which ensured an adequate level of representativeness and reliability of the results. In total, 108 test runs were performed. Table 5 summarises the mean moisture values for the individual salt solution concentrations (0%, 0.5%, 1%, 1.5%, 2%, 2.5%), determined using both the laboratory method and the dielectric method. For specimen identification, the X/Y scheme was adopted, where X denotes the solution concentration and Y is the specimen number written in Roman numerals

In total, 108 moisture measurements were carried out on ceramic brick specimens previously saturated with sodium chloride (NaCl) solutions with concentrations of 0%, 0.5%, 1%, 1.5%, 2% and 2.5%. The material moisture content was determined using two methods: the laboratory (gravimetric) method and the indirect dielectric method. The obtained results are summarised in Table 5.

Based on the data analysis, a clear relationship was observed between the salt content in the material and the difference between the actual moisture content and the reading from the dielectric meter. For specimens without salts (0%), the dielectric method showed a slight underestimation of moisture relative to the reference values, with an average deviation ranging from –0.92 to –3.45 percentage points. In contrast, for salt-containing specimens, a systematic overestimation of the readings was observed, and its magnitude increased with increasing salt concentration.

For example, in specimen 2.5/III, the actual mass moisture content was 7.17%, whereas the dielectric measurement indicated 22.10%, which corresponds to an absolute error of 14.93 percentage points and a relative error exceeding 200%. Similar discrepancies were also found in other highly salt-contaminated specimens, such as 2/II and 1.5/III, where the differences between the actual values and the meter readings were significant and exceeded 12 percentage points.

The mean relative error for the individual salt concentration groups clearly exhibits an increasing trend: for a concentration of 0.5% it amounted to +13.8%, for 1.5% it already reached +88.1%, and for 2.5% it attained +140.5%. This relationship is illustrated in the graph (Fig. 10), which shows an exponential increase in measurement error as a function of salt concentration in the material.

In addition to quantitative differences, significant qualitative discrepancies in the moisture distribution were also observed. Based on the moisture maps obtained using the dielectric method (Fig. 1 and Fig. 3), local anomalies were identified – zones with overestimated moisture readings in the upper parts of the walls, which did not correlate with the typical profile of capillary rise. In these same areas, according to field observations, salt efflorescence and surface damage characteristic of salt crystallisation were visible.

Table 5. Moisture content results determined by laboratory and dielectric methods. Source: own study

Solution concentration	Sample no.	Moisture [%]	
		Laboratory method	Dielectric method
0%	0/I	4.97	4.05
	0/II	9.83	6.80
	0/III	14.25	10.80
0.5%	0.5/I	6.93	5.06
	0.5/II	10.12	11.55
	0.5/III	12.23	17.65
1%	1/I	4.98	8.43
	1/II	10.36	13.75
	1/III	14.29	18.65
1.5%	1.5/I	2.33	0.70
	1.5/II	3.17	8.30
	1.5/III	5.88	18.50
2%	2/I	2.20	1.00
	2/II	4.80	16.90
	2/III	7.86	18.90
2.5%	2.5/I	2.49	1.40
	2.5/II	5.42	19.70
	2.5/III	7.17	22.10

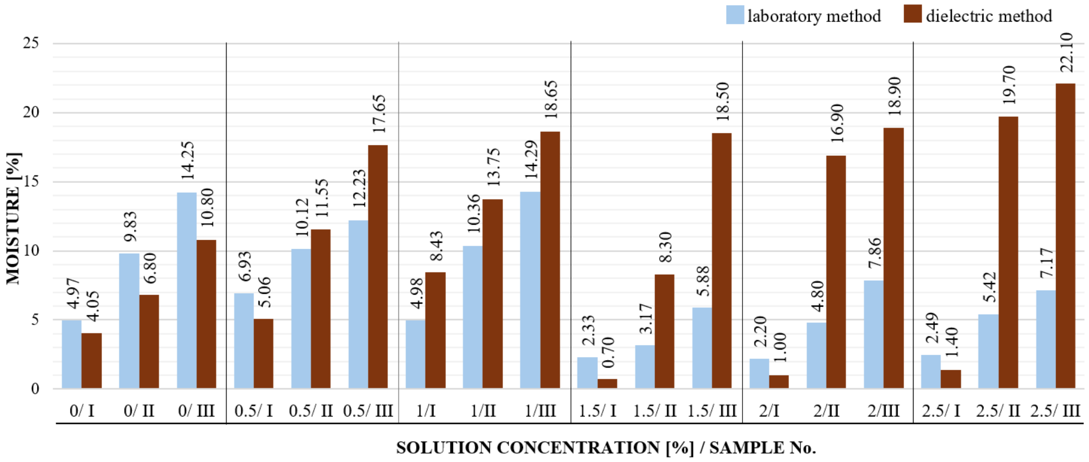

Fig. 10. Graph showing the difference in moisture content determined by laboratory method and measured by dielectric method. Source: own study

5. Discussion

The conclusions obtained in the present study are fully consistent with the results reported in the investigations by Pala and Hoła [15]. Using the resistance method, the authors demonstrated that salts (nitrates, chlorides and sulphates) lead to a systematic overestimation of moisture readings. Errors on the order of 60–70% were observed at medium concentrations and even above 100% at high concentrations, irrespective of the type of salt. Their study also yielded high correlation coefficients between salt content and the distortion of the readings.

Both the dielectric and the resistance methods are based on measuring the electrical properties of the material, which change significantly in the presence of ions. Therefore, the results of these studies are consistent and mutually confirm one another: the presence of salts disturbs the readings of meters calibrated on salt-free specimens, leading to erroneous interpretations of moisture content.

Confirmation of these observations can also be found in a separate publication by Pala which focuses exclusively on the dielectric method. The author demonstrated that, with increasing salt contamination of ceramic brick, the moisture readings obtained from the dielectric meter were systematically overestimated, despite no increase in the actual moisture content. This study clearly confirms that the presence of soluble salts (mainly sodium chlorides) leads to significant disturbance of the signal recorded by dielectric meters, making them unreliable for in situ applications in salt-contaminated materials.

Recent studies, including those by Blaschke et al. [24] and Sass et al. [25], also confirm the limitations of electrical methods in the diagnosis of salt-contaminated materials. Blaschke demonstrated that, in the case of historic bricks containing soluble salts, standard dielectric methods are unable to distinguish between the water content and the conductivity of pore solutions, which leads to erroneous readings.

In response to this problem, the authors proposed the use of broadband ground-penetrating radar (GPR) dielectric measurements in the 1–3 GHz range, which makes it possible to separately assess the influence of water and salts on the signal. A similar approach was presented by Frenzel et al. [26], who used artificial intelligence to process radar signals and eliminate the influence of salt contamination. The results of these studies show that advanced electromagnetic methods have the potential to overcome the limitations of conventional dielectric techniques; however, their application requires specialised equipment and careful calibration.

In turn, Zhao et al. [27] analysing clay plasters from the Mogao Grottoes, showed that the presence of salts (NaCl and Na_2SO_4) radically increases the hygroscopicity of the materials, which leads to falsely elevated moisture readings even at low relative air humidity. This phenomenon also explains the results of the present study, in which specimens with low actual moisture contents exhibited dielectric readings corresponding to a material that appeared "wetter" by more than a dozen percentage points.

The obtained results clearly confirm the significant influence of salt contamination on measurements performed using the dielectric method. The presence of salts leads to systematic and considerable measurement errors, which renders this method unreliable in the case of masonry with elevated salt content. Consequently, it should not be used as a stand-alone technique, but rather as a supporting tool, applied in combination with the gravimetric method and chemical analysis of the material in order to obtain reliable diagnostic results for moisture conditions in historic buildings.

6. Conclusions

Based on the laboratory tests carried out and the analysis of the moisture measurement results obtained using the dielectric and gravimetric methods, the following clear conclusions can be drawn:

1. The presence of salts has a significant impact on the reliability of moisture measurements performed using the dielectric method – in salt-contaminated specimens, systematic and substantial overestimation of moisture readings was observed compared with the actual values determined by the reference method. The higher the salt concentration in the material, the greater the measurement error; for the highest concentration tested (2.5%), relative errors exceeding 140% were recorded.
2. The measurement error increases exponentially with increasing salt concentration in the material. This relationship has been confirmed both statistically and graphically, and its nature clearly indicates that the influence of salt contamination must be considered when interpreting dielectric measurements.
3. Irregularities in the moisture distribution identified by the dielectric method correlate with the presence of crystallising salts in the upper parts of the wall. This phenomenon leads to erroneous interpretations of the direction of moisture migration and may result in an inappropriate selection of design solutions.
4. Despite its convenience and speed, the dielectric method should not be used as a stand-alone tool for the diagnosis of salt-contaminated building envelopes. Its application should be limited to preliminary investigations, and the results obtained must be verified by the gravimetric method and chemical analysis of the material.
5. The results obtained are fully consistent with both national and international literature. This consistency confirms the universal nature of the observed phenomenon and its importance for conservation practice.

Calibration of dielectric meters for a specific building with a known level of salt contamination can reduce measurement errors; however, it requires prior calibration tests based on reference methods.

In summary, the dielectric method does not meet reliability criteria in the case of salt-contaminated masonry and should not be treated as an independent diagnostic tool in the conservation of historic buildings. It remains essential to apply an integrated approach combining different measurement techniques and chemical analyses, in accordance with RILEM and WTA recommendations.

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