Determination of moisture content of the outer wall using hf-sensor technology

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ABSTRACT. This paper describes the measurement of moisture using the hf-microwave method. The reconstruction of the Elbphilharmonie Hamburg, formally known as Kaiserspeicher A, serves as basis for this study of the method [1]. A grid pattern is applied to measure the moisture content using three different microwave sensor application systems. Since the measurement technique is an indirect detection method to determine the relative permittivity of a material, there is a need of calibration of sensors and material. A number of gravimetric moisture measurements of bricks from the Elbphilharmonie Hamburg are used to calibrate each sensor. The advantage of the indirect method is the non-destructive technique.

KURZFASSUNG. Der Beitrag behandelt die Feuchteuntersuchung mit der hf-Mikrowellenmethode am Beispiel des Bestandsmauerwerkes für Umbau- und Sanierungsmaßnahmen am Kaispeicher A zur heutigen Elbphilharmonie Hamburg [1]. Die dafür notwendige Rasterfeuchtemessung wurde mittels hf-Messung mit drei verschiedenen Mikrowellenapplikatoren durchgeführt. Bei dem Messverfahren handelt es sich um eine indirekte Messung, die auf der Bestimmung der Dielektrizitätszahl eines zu untersuchenden Mediums basiert. Der Vorteil der indirekten Messung ist hier, dass es weitestgehend zerstörungsfrei durchgeführt werden kann. Die Messung wurde durch gravimetrische Feuchtebestimmung an dem Mauerwerksziegel der Elbphilharmonie kalibriert.

Keyword: grid pattern moisture measurement, hf-microwave measurement, gravimetric moisture measurement, calibration

1 Introduction

During construction, moisture detection is used to evaluate the drying and drying duration. The results of the measurement show the profile and the origin of moisture in the wall. Evaluating the drying process prevents the enclosure of moisture in the walls during the construction phase. Trapped moisture would lead to wedging caused by frost and mineral efflorescence.

The use of indirect methods demands the calibration of each measurement for the corresponding sensor application. Therefore, additional gravimetric analyses are necessary to determine a specific calibration function of the tested material for each sensor applicator. In the following paper, these functions for the investigated bricks are presented.

For practical use, randomized measurement points that represent different levels of moisture are positioned on each side of the building. At these points, the moisture content is determined by four different hf-applicators. Additionally, some specimens were taken at measurement points for the gravimetric moisture determination. The penetration depth of each sensor varies between 0 to 1cm, 0 to 5 cm, 0 to 9 cm and 0 to 20 cm. Measurements from each sensor and point create a map of specific moisture profiles for walls that are orientated differently. These profiles lead to the origin of the moisture and show, beside the pure moisture content, if the moisture enters mainly from outside, from driving rain seeping through the wall, or from inside of the building during the construction phase. Furthermore, the horizontal and vertical course in which the moisture travelled is shown. The accompanying photo documentation from the status of the building, especially the outside walls, aids the evaluation of the moisture profile.

2 Moisture Measurement

2.1 Measurement method

At the site a randomized grid pattern for measuring the moisture content of the wall is created with the hf-sensors (MOIST- line, from the company “hf-sensor“). The microwave hf-method has been chosen because of its non-destructive testing. The hf-measurement principle is centered on determining the real permittivity of the tested material. The apparent permittivity of water (ε_{Wasser} ~ 80) is much higher than that of common building materials ($\varepsilon_{Baustoff}$ ~ 4-7), hence the moisture content leads to significantly higher measurement values.

Moreover, there is, even in the case of a technique using microwave, a small loss of permittivity, which cannot be neglected and have to be recognized in the development of the calibration function.

Additionally, with the increase of electric frequency, the influence of ohm loss decreases, as in the case of salt penetrating the wall. At the frequency of 1 GHz the influence of ohm loss is very low compared to the loss of permittivity, but should also not be neglected. The surveillance system sensors preferably measure in a frequency range of 2 to 10 GHz. [2].

Interaction principles of technique using microwave applicators allow the variation of the penetration depth for the measurement system. The penetration depth of the sensors ranges between 0 to 3 cm, 0 to 5 cm, 0 to 9 cm and 0 to 20 cm [3].

A view of the cross section through the wall and the penetration depth of the corresponding sensor applicator is given below:

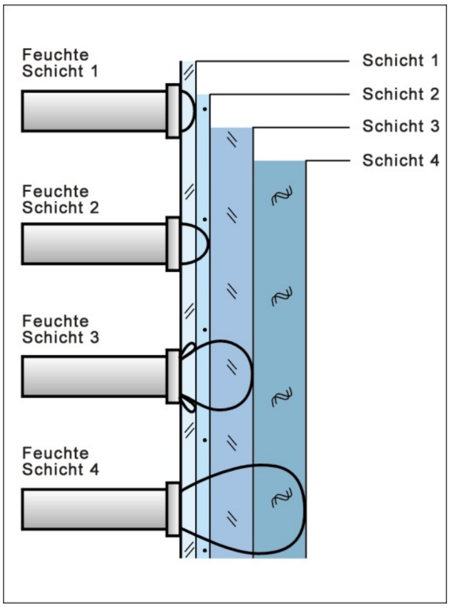

Fig. 1: Depth of the measurement applications, source hf sensor GmbH Leipzig.

The measurement system works with a detection system using the reflection technique which makes it possible to put the sensor on top of the analyzed material. The material surrounding the sensor also influences the measurement. The following radii around the sensor influence the measurements [4]:

- Stray magnetic field => ~ 3 cm
- Radiation antennas sensor => 10 – 15 cm

2.2 Calibration

Indirect measurement methods require calibration of the sensor results. Hence, after measuring the moisture content of the wall with the hf-method, representative points are selected to take material samples. They are made by dry drilling at low speed, not to change the moisture quantity of the sample or by taking whole bricks break out the core with a chisel. Afterwards, the sample is wrapped air- and vapour tight. After removing entire brick, they are cut at depths corresponding drilling. In the laboratory, the moisture content of the sample is measured by thermo gravimetric method. Therefore, the moist samples are weighed and afterwards dried in a special oven at 105°C, until the mass constancy, according the German standard DIN EN ISO 12570. Subsequently the samples are weighed again. The moisture content is obtained from the difference between the moistened weight and the dry weight. The moisture content related to the dry weight of the sample is expressed in M-%. The recognition of the gross density converts the result into [kg/m³].[5]

Fig. 2: A tapping point of entire brick sample, 2^{nd} floor northern facade.

The mean value of each measured depth is summarized to derive the specific calibration function for the corresponding microwave-applicator in combination with the bricks of the Elbphilharmonie Hamburg. Since the hf-measurement is done at 4 different penetration depth of the wall, the result from the gravimetric measurement could positively correlate with the scale of the hf-sensor.

The calibration graphs for the four sensors depicted in figure 3 exhibit a linear behaviour; the functions are described correspondingly.

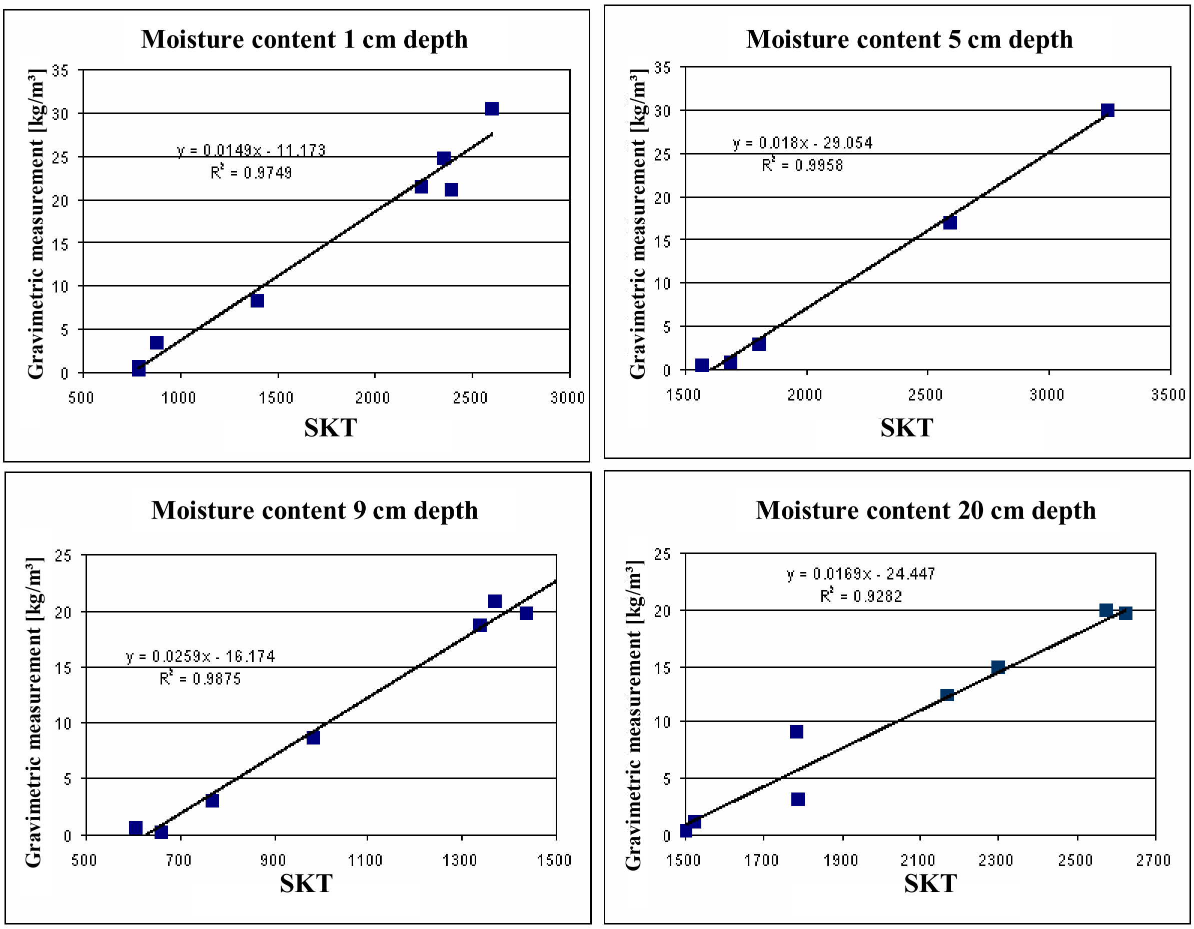

Fig. 3: Calibration functions for the bricks of the Elbphilharmonie Hamburg for all four microwave-applications sensors.

3 Results

3.1 Moisture content of the brick walls

Taking the calibration with the corresponding sensor into account, the actual moisture content of the wall is directly given. Thereby, the moisture content of the facade is directly examined in situ, with use the sensors for different penetration depths. Measuring the moisture content at one point at different depths gives an idea of the origin of the moisture. It can be determined if the moisture comes from outside, for example from rain seeping into the wall or if the water originates from inside during the construction phase.

Since the results vary for walls of the same orientation, mean values for the moisture content separated by the levels of the building are shown below in table 1 to 4. For each level, the measurements are taken at 1 m and 2 m above the floor.

Table 1: Mean values of the water content from the inner wall surface from 0 to 1 cm, divided into levels and orientation of the wall.

	0-1 cm inner wall surface				
	north	south	west	east	mean value
	Vol % moisture content				
6. floor 2m		2.5		9.3	5.9
6. floor 1m	9.7	4.8		10.8	8.4
5. floor 2m	13.3	5.6	8.7		9.2
5. floor 1m	12.7	6.8	1.9		7.1
4. floor 2m	0.3	11.3		9.7	7.1
4. floor 1m	0.8	7.8		8.9	5.8
3. floor 2m	14.6	20.6	12.9		16.0
3. floor 1m	15.2	21.0	14.2		16.8
2. floor 2m					
2. floor 1m	9.8	5.8			7.8
mean value	9.5	9.6	9.4	9.7	9.5

Table 2: Mean values of the water content from the inner wall surface from 0 to 5 cm, divided into levels and orientation of the wall.

	0-5 cm inner wall surface				
	north	south	west	east	mean value
	Vol % moisture content				
6. floor 2m		2.7		14.2	8.4
6. floor 1m	21.4	8.1		18.5	16.0
5. floor 2m	14.5	5.9	12.8		11.1
5. floor 1m	12.8	5.9	3.7		7.5
4. floor 2m	0.7	12.5		15.6	9.6
4. floor 1m	0.1	12.5		12.6	8.4
3. floor 2m	17.5	14.0	13.8		15.1
3. floor 1m	18.6	14.0	19.1		17.2
2. floor 2m					2.0
2. floor 1m	14.0	4.5			9.2
mean value	12.4	8.2	12.3	15.2	11.2

Table 3: Mean values of the water content from the inner wall surface from 0 to 9 cm, divided into levels and orientation of the wall.

	0-9 cm inner wall surface				
	north	south	west	east	mean value
	Vol % moisture content				
6. floor 2m		4.2		11.9	8.1
6. floor 1m	9.7	5.7		7.9	7.8
5. floor 2m	11.8	3.5	12.8		9.4
5. floor 1m	9.7	4.9	3.7		6.1
4. floor 2m	0.8	9.5		9.6	6.6
4. floor 1m	2.2	3.4		8.6	4.7
3. floor 2m	14.0	3.0	2.8		6.6
3. floor 1m	14.2	3.0	15.4		10.8
2. floor 2m		2.0			2.0
2. floor 1m	13.8	2.0			7.9
mean value	9.5	4.1	8.7	9.5	7.3

Table 4: Mean values of the water content from the inner wall surface from 0 to 20 cm, divided into levels and orientation of the wall.

	0-20 cm inner wall surface				
	north	south	west	east	mean value
	Vol % moisture content				
6. floor 2m		3.7		11.6	9.6
6. floor 1m	13.6	6.1		9.5	7.8
5. floor 2m	11.5	4.7	14.4		10.2
5. floor 1m	10.7	5.8	5.7		7.4
4. floor 2m	4.2	11.8		10.3	8.8
4. floor 1m	6.6	12.8		7.5	9.0
3. floor 2m	14.5	15.3	11.6		13.8
3. floor 1m	13.0	19.8	13.2		15.3
2. floor 2m					
2. floor 1m	11.8	10.1			10.9
mean value	10.7	10.0	11.2	9.7	10.4

The results of the individual measurements are heterogeneous and show that some areas are nearly saturated, while other areas are relatively dry. When the measurements are grouped, the mean values become more homogenous and give a generalized view of the walls overall moisture content.

The influence of driving rain is shown by the high water content of the west-, north- and eastward exposed facade. The southwards exposed facade has lower water content especially at the outside. Particular if driving rain appears, the moisture profile shows higher moisture content at the outside, while the inside of the wall is dryer.

The examination of the building levels shows, especially on the third floor, the moisture originates from inside of the building into the wall. This can be explained by water accumulate in puddles on the concrete floor and running along the wall from the upper level resting on the floor of lower levels. The observed regions were more or less separated from the outside so there was little natural ventilation. Hence the moisture could not drain [6] [7] [8] [9].

For evaluation of the moisture content of the walls, additionally the maximum absorbable moisture content was measured. Furthermore, the moisture content of nearly saturated air is measured.

Along the inner surface of the walls the moisture increases again. That shows there is still water coming from inside the building. One typical distribution of water content for each site of the building is given in figure 4.

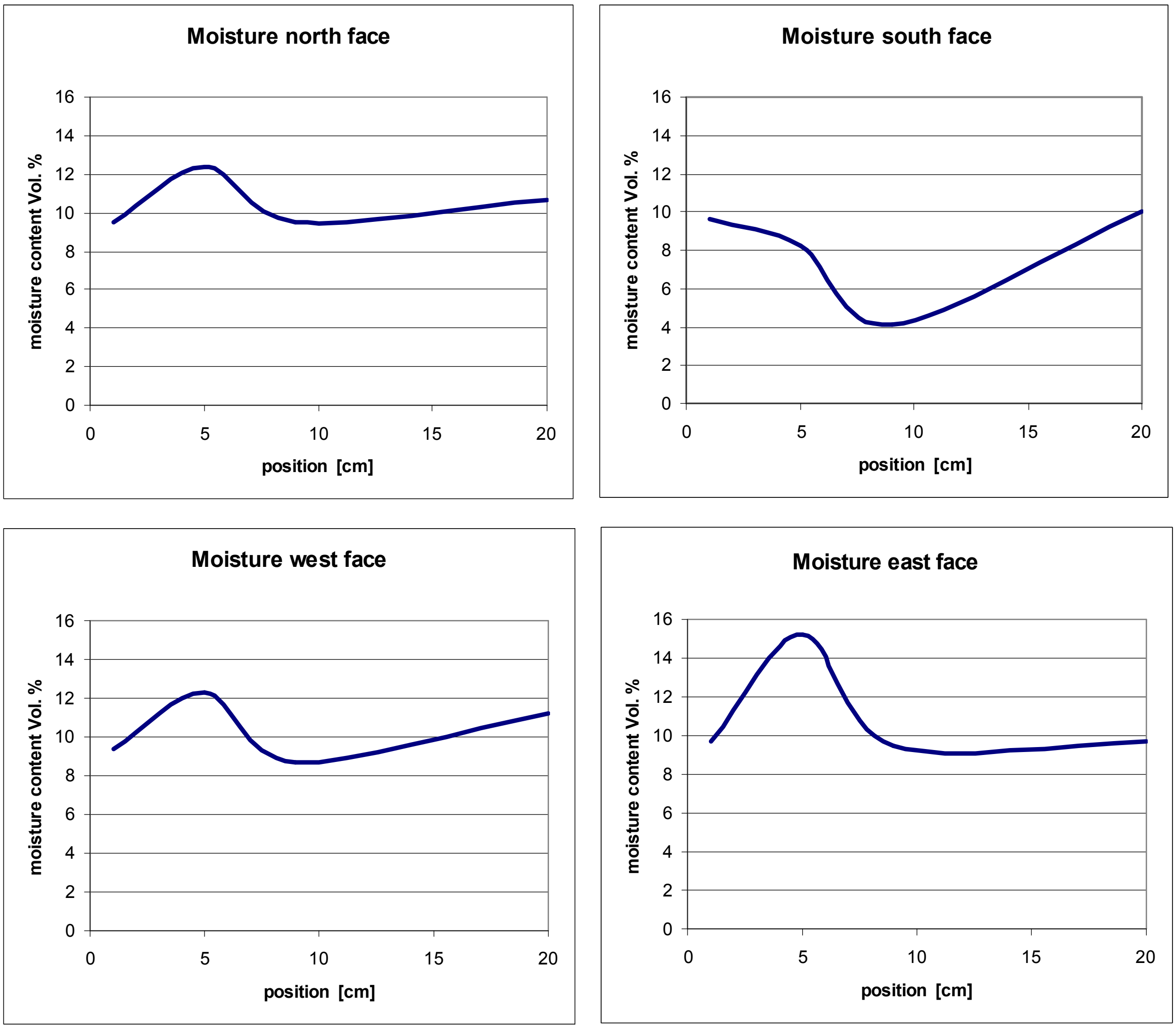

Fig. 4: A typical moisture distributions of the four differently orientated walls.

To evaluate the values of humidity from in situ measurement the maximum possible moisture content of the brick Elbphilharmonie was determined in the laboratory, according the German standard DIN EN 13286. The moisture content near moisture saturated climate was also measured in the laboratory according the German standard DIN ISO 12571 [10] [11] .

The entire investigation includes 324 individual measurements and concludes that on average the walls have a moisture content of 7 up to 11Vol%. Since the brick is characterized by 0.45Vol% of moisture at 97.4% of relative humidity, this high moisture contend can only be explained by the damp of water during the construction.

From the deviation of the result, it is evident that the walls are moistened from the inside and from the outside of the building. The graphs show that the measured outside areas of the walls are nearly saturated by moisture. While the inside of the walls are dry.

4 Conclusion

Each hf-sensor needs an individual calibration for each investigated material. In particular for old building materials, the material properties may change during time and requires to be currently evaluated. The calibration data required are obtained from a few samples by measuring the moisture content using thermo gravimetric method. From this data the calibration curves are derived by linear regression.

The hf- sensor applicators allow a non-destructive testing of brick walls. The combination of sensors with different penetration depth delivers moisture profiles of a wall.

The results show that the walls of the Elbphilharmonie Hamburg have heterogeneous moisture content with infiltration of water from outside resulting from driving rain and from inside the building, cause by moisture ponding on the concrete floors and wall run off.

5 ACKNOWLEDGEMENTS

I am very grateful to be supported by the European Structural Fund and the Free State of Saxony by the project number: 80937456.

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