Documentation of moisture reduction up to two years after refurbishment of moisture damaged exterior basement wall

Høegh, Britt Haker; Vanhouttegehem, Lies; Hansen, Thor

Published in:
NSB 2023 - Book of Technical Papers: 13th Nordic Symposium on Building Physics

DOI (link to publication from Publisher):
10.54337/aau541578714

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Documentation of moisture reduction up to two years after refurbishment of moisture damaged exterior basement walls

B H Høegh[1], **L Vanhouttegehem**[1] **and T Hansen**[1]

[1] Danish Technological Institute, Gregersensvej 1, 2630 Taastrup, Denmark.

brh@teknologisk.dk

Abstract. In Denmark, many old buildings are constructed with massive masonry basement walls. Originally, these basements were used for storage or as boiler room. Hence moisture in the basement walls was not considered a problem, and moisture protection of basement constructions was not considered necessary. However, leaving older buildings basement walls exposed to moisture from the surrounding soil, results in a high risk for damage and mould growth on the interior surface of the exterior basement walls. Today, many of these basements are used for daily purposes. Accordingly, moisture problems in the basements are no longer acceptable. Therefore, drainage systems in combination with external insulation of the basement walls are installed in many buildings. Traditionally, insulation materials with a high water vapour resistance are used as external insulation for basement walls in Denmark. However, theoretical approach and field experiences indicate that application of insulation materials with a low water vapour diffusion resistance, results in a larger reduction of the moisture content in the masonry of the basement's exterior walls. This paper documents moisture measurements from a basement, in which external insulation with low vapour diffusion resistance was applied to the external basement walls. Additionally, at the bottom of the basement walls a horizontal moisture barrier and perimeter drain were installed, as well as heating and natural ventilation of the basement. After one year, a noticeable reduction in moisture content was measured compared to the moisture content before installation, while no further reduction was seen after the second year.

1. Introduction

Many basements in Denmark are affected by moisture from surrounding soil and rising damp. This results in a high risk for damages and mould growth, not only on the interior surface of the exterior basement walls, but also in wooden beam ends of the joist floor above the basement, and on the interior and exterior surface of the exterior walls above terrain. Especially buildings from the late 18th and early 19th century, which are typically constructed with brick walls [1], are in risk, as the capillary suction in masonry walls with lime mortar can be several meters high.

Still, the residents use the basement e.g., as laundry or bike storage. To reduce the risk of mould growth and associated odour problems, measures to reduce the moisture content in the basement's exterior walls are often installed. These include for example the installation of a drainage system. As the earth around the building is dug up for installing the drainage system, this is usually combined with exterior insulation of the basement walls. Exterior insulation has a positive impact on the moisture conditions on the inner surface of the basement walls and on the building's energy consumption.

In Denmark, the exterior surface of the basement walls is typically tightened with a waterproof membrane, and an insulation material with a high water vapour resistance is used, to cut off soil dampness from the outside [2]. However, the masonry basement walls of buildings established before the 1980's are normally not only affected by soil dampness from the outside. In masonry walls, rising damp from underneath the building constitutes another significant moisture source, that cannot be stopped by the installation of a drainage system and by tightening the outside of the basement walls. At the same time, the use of water and diffusion tight materials prevents moisture transport from the masonry to the outside.

To allow for this moisture transport, insulation materials with a low vapour diffusion resistance should instead be used as external insulation of basement walls. A theoretical study on the effect of exterior insulation of basement walls with an insulation material with low water vapour resistance has shown that this results in a lower moisture level in the basement walls and in a higher drying speed of the masonry [3]. However, the use of water vapour open materials on the outside of the basement walls still requires that the basement walls and the subjacent foundations are protected from ground water by use of perimeter drains, sometimes complemented with sub-slab drainage or a horizontal moisture barrier. In this paper, field experiences and moisture measurements with different measurement methods are presented for a case study building, in which insulation with a low vapour diffusion resistance was used for external insulation of the basement walls.

2. Description of the case building and the installed moisture reduction measures

The case building is a multi-story building established in 1906, situated next to a lake in Copenhagen city, where the ground water level is high. The basement has a floor area of 166 m^2 and a clear height of 140 cm. The joist floor above the basement starts approximately at terrain level.

The basement's exterior brick walls are 500-610 mm thick and placed directly on clay ground. The partition brick wall to the neighbouring building is 360-480 mm thick. Originally, the exterior basement walls were treated with asphalt on the outside, which is typical for the building period in Denmark. The inside rendering (lime mortar) of the basement walls appeared with efflorescence and peeling.

The existing ground slab in the basement consists of a non-reinforced concrete ground slab (ca. 5 cm) placed on a layer of pebbles. In the pebbles layer, sub-slab drainage pipes were placed along the inside of the brick wall foundations and connected to a well. The pipes were silted up. On the outside of the basement walls, a perimeter drain was installed in the early 2000's.

In June 2016, a first series of moisture measurements was performed with the Troxler gauge (see chapter 3.2) to investigate the moisture content and the height of rising damp in the exterior walls of the basement and the first floor. From the measurements, it was concluded that the moisture level in the exterior basement walls and in the lower parts of the exterior walls on the first floor was quite high. Therefore, the building-owner's association decided to implement measures to reduce the moisture level in the exterior basement walls and the walls on the first floor to avoid mould growth on the internal surface of the walls and to protect the wooden beam ends in the joist floor above the basement from dry rot. Following measures were installed in 2020 (completed November 2020), see also Figure 2:

- The asphalt layer on the outside of the exterior basement walls was removed.
- 100 mm insulation with low vapour diffusion resistance was installed on the outside of the exterior basement walls. The insulation consists of a bitumen glued expanded polystyrene with 35 % pore volume and thermal conductivity of λ= 0,039 W/(m·K). Measurements for water vapour resistance of the product are not available, but as the material is not airtight and water can run through the material, the water vapor resistance of the material is assumed to be low.
- A geotextile with a low vapour diffusion resistance was mounted on the outside of the insulation.
- New perimeter drainage was laid on the outside of the exterior basement walls.
- The sub-slab drainage pipes were cleaned, and two new wells were established.
- A horizontal moisture barrier of stainless steel was established in the masonry on top of the first course over the basement ground slab. In the exterior basement walls, the barrier was placed over the total thickness of the wall, except behind the boiler, where the barrier was established from the outside, covering only about 75 % of the thickness of the exterior walls. In the partition

wall to the neighbouring building, the horizontal barrier was stopped ca. 20-50 mm from the inner surface in the neighbouring building, to avoid damage.

- All render was removed from the inner surfaces of the exterior basement walls. Afterwards, the surfaces remained untreated.
- Heating was installed in the basement, and the indoor temperature kept at 16-18 °C year-round.
- Natural ventilation was established in the basement to continuously remove moisture from the indoor air. The air outlets were formed as a gooseneck, to lift them over terrain level.

3. Description of measurement methods, measurement positions and time of measurements

This chapter describes the measurement positions and the time of the measurements, as well as the two methods used for moisture measurements in the exterior basement walls. The first method uses the Troxler gauge, the second method uses a hf-sensor.

Measurement positions and time of measurements

For each number marked on the basement plan (Figure 1), measurements were taken at 3 different heights (Figure 2): MH1 at 20-40 cm, MH2 at 60-80 cm and MH3 at 110-130 cm above the ground slab.

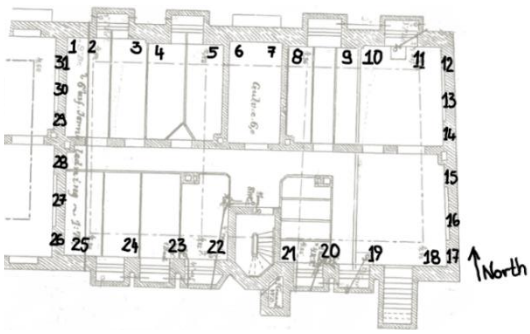

Figure 1. Basement plan with measurement positions. Figure 2 shows measurement heights (MH).

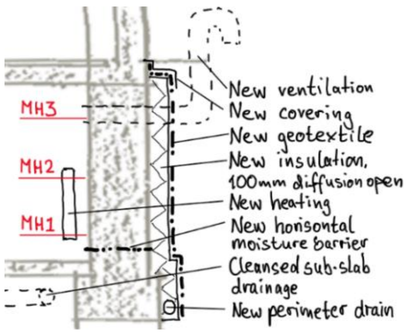

Figure 2. Exterior basement wall with indication of measurement heights (MH) and moisture reduction measures.

The first series of measurements were performed with the Troxler gauge in June 2016, before any moisture reduction measures were applied. As the basement was divided in small storage rooms, no measurements at the interior surfaces of the exterior basement walls in east and west orientation could be performed. In January 2022, one year and two months after the completion of the moisture reduction measures, the second measurement series with the Troxler gauge were performed. At that time, all interior surfaces of the exterior basement walls, except behind radiators and the boiler, were accessible. A third measurement series was performed in November 2022, two years after completion of the moisture reduction measures, using both the Troxler gauge and the hf-sensor.

Moisture measurement with Troxler gauge

Measurements with the Troxler gauge are non-destructive. In most constructions, depending on the included materials, the Troxler gauge registers the moisture content up to a depth of 100-150 mm. The presence of salts or air gaps in the investigated materials or constructions does not influence the moisture measurement. Measurements can be performed at temperatures under 0 °C. [4]

The Troxler system [4,5] is based on a moisture gauge with a small radioactive source. This calibrated neutron source emits a steady stream of fast neutrons into the measured construction. The neutrons are reflected by collision with the atomic nuclei in different materials in the construction. The velocity of the neutrons is reduced significantly in collision with the light hydrogen nuclei bound in both water and in other materials, while heavy atomic nuclei reduce the velocity of the neutrons only slightly upon return. The Troxler gauge counts only the slow neutrons, that are reflected by hydrogen nuclei, and gives a result called the Troxler digit count. The content of bound hydrogen in a material usually varies little. Thus, variations of digit counts, when measuring on the same type of material, reflect variations of moisture content. According to practical experience of the authors, Troxler digit counts on masonry in the range of 8-12 indicate a moisture content of up to 0,8 weight %, digit counts over 50 indicate a moisture content of more than 10 weight-%.

Moisture measurement with hf-sensor

The third series of moisture measurements included moisture measurements with a hf-sensor [4,6]. Different surface sensing heads allow measurements at different depths in a material. In this case, the surface sensing heads MOIST-R2M and MOIST-PM were used, allowing measurement depths of 7 cm and 30 cm, respectively. As with the use of the Troxler gauge, the presence of salts in the investigated materials or constructions does not influence the measurements. However, surface roughness and air gaps have a great impact on measured moisture content. Moreover, metallic objects in the construction must be avoided, and a temperature above 0 °C is required for measurements.

The hf-sensor uses a dielectric moisture measurement method. As water is a polar molecule, water molecules can be forced to orientate in a preferred direction by an electric field. By applying an alternating electromagnetic field, the water molecules will start rotating with the frequency of the field. This rotation (orientation polarization) is described by the dielectric constant (also permittivity). At high frequencies, there will occur dielectric losses. As the dielectric effect of water is much stronger than the dielectric effect of most solid building materials, the dielectric losses of water can be measured as an indication of even small amounts of water in the measured material. The instrument provides the results as moisture content in weight-% for the chosen material.

4. Results

The results of the moisture measurements with the Troxler gauge are shown in Figure 3. The variation of the Troxler digit counts at the different measurement dates and at different heights above the ground slab are shown separately for each of the three exterior basement walls (North, East and South) and for the neighbouring partition wall (West).

The individual results of the basement walls showed a larger moisture reduction in the middle of a wall section e.g., at measurement positions 2, 10, 13, 16, 19 or 23, while the moisture reduction was less

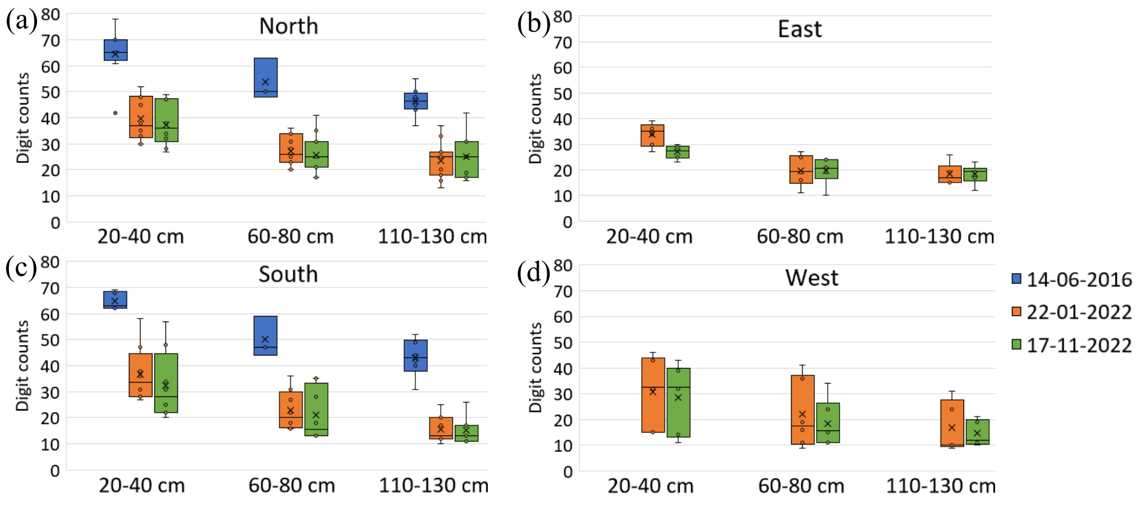

Figure 3. Troxler measurement results on the interior surface of the exterior basement walls at different heights over the ground slab before (blue series), 1 year 2 months after (orange series) and 2 years after (green series) installation of the moisture reduction measures. Graphs a), b), c) and d) represent the three exterior basement walls and the neighbouring partition wall.

in wall areas close to exterior wall corners (positions 11, 12, 17 and 18), close to intersections with partition walls (positions 1, 6, 7, 21, 22, 25, 26 and 31), or at level MH1 behind the boiler (position 9).

In Figure 4 the results of the moisture measurements with the two hf-sensor surface sensing heads are shown separately for each of the three exterior basement walls (North, East and South) and for the neighbouring partition wall (West). The individual results showed higher moisture content in the same wall areas, as for the measurements with the Troxler system i.e., close to outer wall corners, intersections with partition walls and at level MH1 behind the boiler.

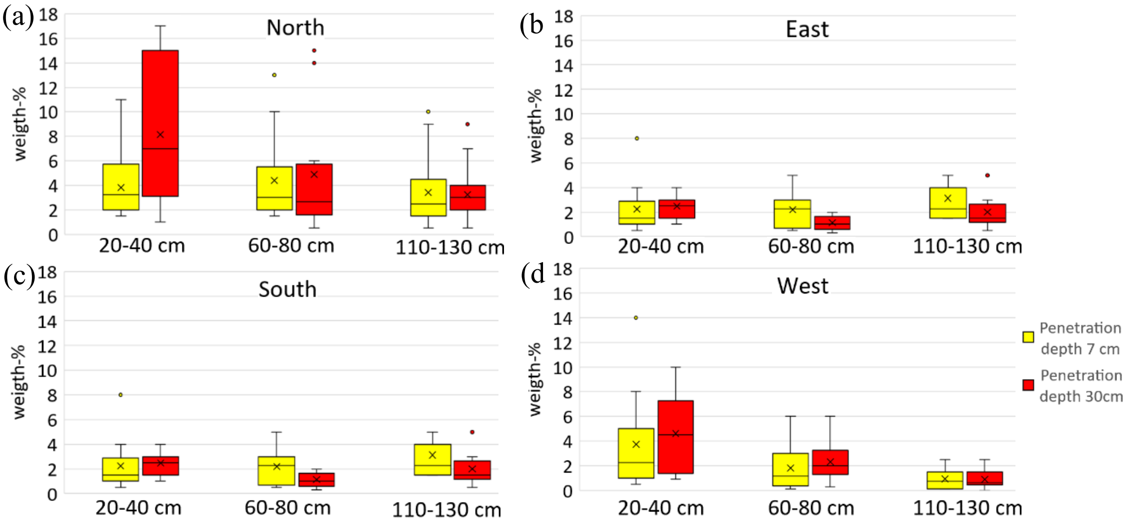

Figure 4. Hf-sensor measurement results at 7 cm depth (yellow) and 30 cm depth (red) on the interior surface of the exterior basement walls at different heights over ground slab, performed 2 years after installation of the moisture reduction measures. Graphs a), b), c) and d) represent the three exterior basement walls and the neighbouring partition wall.

5. Discussion

One year and two months after the installation of the moisture reduction measures, measurements with the Troxler system showed a noticeable reduction of the moisture level at all measurement heights for the exterior basement walls towards north and south (Figure 3, a) and c)). In the following 10 months, no further significant moisture reduction was measured, neither in these walls, nor in the eastern wall (Figure 3, b)) or the neighbouring partition wall (Figure 3, d)).

Comparing the individual results for each wall after the implementation of the moisture reduction measures, a variation in moisture content was seen, which indicates varying moisture reduction in the different parts of each wall. Lowest reduction was seen close to corners, in areas with adjacent partition walls or behind the boiler, where the horizontal moisture barrier only covered 75 % of the thickness of the exterior wall.

Two years after the installation of the moisture reduction measures a moisture content in the exterior basement walls of 0,5-17 weight-% was registered with the hf-sensor. The highest moisture content was measured at height MH1 over the ground slab. At height MH3, close to the joist floor above the basement, a moisture content of 0,5-4 weight-% was measured. To avoid dry rot, the acceptable moisture content in the wooden beam ends should at maximum be 20 weight-%, corresponding to a relative humidity (RH) of 87 % [4]. In equilibrium with 87 % RH, masonry has a moisture content of less than 0,6 weight-% [7]. This criterium was still exceeded in most of the masonry right under the joist floor.

Measurements with the hf-sensor showed similar moisture levels with both sensor heads, indicating the same moisture level at both penetration depths. Only in the northern wall at height MH1 over the ground slab, the results indicate a larger moisture reduction in the surface of the wall than in its core.

Furthermore, measurements with the hf-sensor showed a wider range in measured moisture content, with more outliers in all measurement positions, than measurements with the Troxler gauge. This could be due to the structure of masonry walls. Masonry joints, especially the butt joints, are not totally filled up with mortar when erecting a masonry wall, resulting in remaining air gaps in the structure. Both these air gaps and the roughness of the surface of masonry walls are considered to affect the measurements with the dielectric moisture measurement method used by the hf-sensor, resulting in a larger variation of results.

6. Conclusions

Moisture measurements one year and two months after the completion of the moisture reduction measures showed a remarkable reduction of the moisture content in the masonry of the basement's exterior walls. Although no noticeable moisture reduction was registered in follow-up measurements after 2 years, further moisture reduction is expected, but at a lower speed. Compared to the results of the study in [3], the moisture reduction in this case was faster and more effective. We assume that the fast moisture reduction is related to the installation of heating in the basement, as the elevated indoor temperature in the basement induces the necessary gradient in vapour pressure over the exterior basement wall construction. We assess that this gradient was the driving force for water vapour transport from the masonry, through the exterior vapour diffusion open insulation material, to the surrounding ground. To investigate this further, we suggest hygrothermal simulations of the case-study.

At the same time, the results indicated a positive effect on the moisture reduction by the installation of a horizontal moisture barrier of stainless steel at the bottom of the exterior basement walls and neighbouring partition wall. The effect was though slightly reduced at positions, where the horizontal moisture barrier did not penetrate the whole wall thickness.

The achieved moisture content in the exterior basement walls right under the joist floor above the basement at height MH3, was still higher than expected for masonry walls under normal indoor conditions, and in general still giving conditions for development of dry rot. Thus, moisture protection measures for the wooden beam ends in the joist floor above the basement are still required.

Comparing both measurement methods, we suggest more measurement positions in a smaller measurement grid, when using a hf-sensor compared to the Troxler-gauge, in order to reduce the influence of air gaps in the masonry joints and obtain reliable measurement results.

7. Acknowledgments

Measurements were performed partly on demand of the building-owner's association and partly as activity in a project supported by the Ministry of Higher Education and Science. Thanks to the building-owner's association and especially to Max Lord for consenting to supplementary measurements and to the publication of the results of the project.

References

[1] Engelmark J 1983 *Københavnsk Etageboligbyggeri 1850-1900. En Byggeteknisk Undersøgelse* (Hørsholm: Statens Byggeforskningsinstitut) pp 135 ff.

[2] Brandt E, et al. 2022 *SBi-anvisning 279 Fugt – Bygningsdele* (Danmark: BUILD, Aalborg Universitet)

[3] Geving S, Kvalvik M and Martinsen E 2011 Rehabillitation of basement walls with moisture problems by the use of vapour open exterior thermal insulation *9th Nordic Symposium on Building Physics* (vol 1) (Amsterdam: North-Holland/American Elsevier) pp 323-300

[4] Brandt E, et al. 2022 *SBi-anvisning 277 Fugt – Theori, beregning og undersøgelse* (Danmark: BUILD, Aalborg Universitet)

[5] 2006 *Instruction Manual Model 3216 Roof Moisture Gauge* (Troxler Electronic Laboratories, Inc.: Durham, NC, USA)

[6] hf sensor GmbH, Leipzig, Tyskland located at www.hf-sensor.de

[7] Kielsgaard Hansen K 1986 *Technical Report 162/86 Sorption Isotherms A Catalogue* (Danmark: The Technical University of Denmark)