REDUCTION OF MOISTURE IN BASEMENTS OF BUILDINGS

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Abstract. The paper is focused on the problems of increased humidity in the structure of buildings, both modern new buildings, but especially in old buildings, which have usually very poor insulation against ground moisture, or there have been changes in the subsoil. These problems are described in details and according to the situation of the building quality and its use the possible reconstruction is recommended. By the reconstruction the comfort inside buildings should be increased and thus satisfactory hygienic requirements achieved for health of people or possible use for other purposes. This will prevent also possible degradations of the walls and static problems of the building. All renovation methods are compared in terms of the costs of their implementation. As an example of practical realization an underground room in an old building in Prague was chosen. The measurements showed a totally unsatisfactory situation in this room, so the reconstruction was designed to improve the current situation. The comparison before and after reconstruction provides practical experience of the positive and negative aspects of the proposed and verified solution. The obtained results from this measurement and findings may be useful for further research in this issue as well as for practical solutions for similar problems in many older buildings.

Keywords: insulation, humidity, reconstruction, temperature.

Introduction

Moisture of walls in the basement and ground floor of the building is now a common problem that must be resolved during reconstruction of old buildings, which generally have insufficient moisture barrier. In some cases, there are problems with damp structures and high internal humidity, even in new houses. The use of basement as a living or working space requires ensuring a comfortable indoor climate and prevention of condensation and mold formation [1].

Basement and floors interact with soil moisture and its microbes. Some people are sensitive to mold allergens and have serious health problems in such environments [2]. Several epidemiological investigations concerning indoor environments have indicated that “dampness” in buildings is associated to health effects such as respiratory symptoms, asthma and allergy. The review shows that “dampness” in buildings appears to increase the risk for health effects in the airways, such as cough, wheeze and asthma. There also seems to be an association between “dampness” and other symptoms such as tiredness, headache and airways infections. It is concluded that the evidence for a causal association between “dampness” and health effects is strong [3].

Water penetrates into the walls in a liquid and gaseous state. Water moisture gets into the structure by diffusion of water vapor by capillary action of humidity and capillary condensation. These effects are reflected on the construction by dark and salt spots on the surface of a wall, a gradual sloughing of the walls and supporting structures disruption. Further, these phenomena manifest themselves by raising the humidity in rooms, thereby by worsening the use of the space in terms of hygiene. Two years after the reconstruction work, the microclimate in the basement of the Palace of Signatories has deteriorated [4]. Excess moisture has caused salt efflorescence, staining of the exterior walls and ceilings and spread of an unpleasant smell throughout the building. The tests showed that damp-proofing of the basement exterior walls was inadequate. Dampness has caused salt efflorescence on the facing of the basement walls and other building structures.

Water acting on the structure can be of atmospheric origin, subsurface or internal operation and use of the room. Atmospheric water is rainfall which runs down the structures or seeps into the soil near the building. Subsurface water is contained in a natural environment and is bound by sorption and capillary forces. By capillary action it penetrates into the structure at the missing or damaged surface waterproofing membrane.

Operating humidity is released from various sources of humidity indoors in the air such as mainly by people, plants, technical equipment in the bathroom, the kitchen and oven, or from technological equipment in the workshop etc. When the temperature of the walls falls below the dew point on the surface condensed water from vapor occurs, e.g., in corners, on parapets around the windows, in places of thermal bridges etc.

A new approach to moisture detection in buildings by an optical infrared thermography method is presented in several papers [5-7]. Infrared thermography was used to map moisture distribution and to identify areas with anomalous water content in modern and ancient building structures.

Water can migrate through basement walls due to hydrostatic pressure, capillary action, and vapor pressure. An attempt was made by the developer to stop the leakage through the basement walls by applying a waterproofing membrane to the interior wall surface, but this did not stop the moisture infiltration. The problem could have been avoided if the developer had noticed the height of the waterproofing membrane in relation to the final finish ground surface during construction [8].

There are many methods for reduction of moisture in walls [9]. The first group of methods covers methods that prevent the moisture causes. Missing or defective waterproofing can be replaced or repaired by additional insulation (strip, foil, sheet etc.), embedding insulation foil along the walls in trench or by horizontal and vertical aperture by infusion drilling. These methods are in the long term for buildings favorable.

The second group of methods includes measures restricting the effects of moisture, but the moisture penetrates into the structure and disrupts it. That is, e.g., new plasters and coatings, electro-osmosis, construction work surroundings, drainage and air blow treatment.

Rather important for the application can be also in some cases the cost of reconstruction. Average prices per m^2 of some reconstruction and improvement methods are summarized in Table 1.

Table 1

Average price of individual treatment methods

Method	Price, EUR·m^{-2}
Undercutting of brick wall and embedding of plate insulation	81-119
Undercutting of other types of wall and embedding of plate insulation	144-200
Insulation by surface chemical injection	144-219
Reverse insulation by injection through walls	59-85
Embedding of stainless steel sheets in walls	104-130
Embedding insulation foil along walls in trench	59-63
Installing special sanitation plasters	20-48
Electro-osmosis (active range of device 30 m)	1333

The aim of this paper is to show the example of a subterranean basement room with high moisture on the walls. There are presented typical features and symptoms of high humidity, suitable and available methods of measurement, assessment and the method for identifying the sources of moisture in the wall. At the end of this paper there is also shown a simple method of improvement of internal environment in that basement underground room.

Materials and methods

To verify the described techniques an underground basement room with a total area approximately 30 m^2 in an apartment building in Prague district from the early 20^{th} century was chosen. The room is not a flat; it is used only as a club for meeting of school children in their free time several times per week. The house was fully renovated in 2009. Problems in this basement room, however, continue after the overall reconstruction. The reasons are poorly made outdoor vertical insulations and capillary rising water. The floor plan of the room is given in Fig. 1. The external walls are constructed from the traditional brick masonry with a thickness of 750 mm.

The first measurements were carried out before the improvement of the walls in two periods. First, in normal weather conditions (during average external temperatures -1.5 ± 2.9 ºC and relative humidity 62.8 ± 16.3 %) and later also during rainy weather (during average external temperatures 9.9 ± 3.5 ºC and relative humidity 75.4 ± 13.7 %) with the aim to analyze the existing indoor conditions and identify the source of moisture problems. The second part of measurements was carried out after the improvement of the walls during average external temperatures 1.6 ± 0.9 ºC and relative humidity 81.1 ± 7.2 %.

Air temperatures and relative humidity were measured by data loggers ZTH65 in two parts of the room (near to the wet wall with high air humidity and near to the dry wall with low humidity) with registration at intervals of 15 minutes during one week (long-time measurement). The parameters of ZTH65 are: temperature operative range -30 to +70 ºC with accuracy ±0.4 ºC and operative range of relative humidity 5-95 % with accuracy ±2.5 %.

For indirect measurement of wood moisture the capacitive sensor FH A696-MF with operative range of mineral construction materials from 0 to 20 % with accuracy 0.1 % was used. The sensor was connected to the data logger ALMEMO 2690-8.

The surface temperatures of the walls were measured by the thermographic camera IR Flexcam Pro with operative range from -30 to +350 ºC with accuracy ±2 ºC. Instantaneous values of surface temperatures (thermograms) were stored in the device memory and then analyzed in a PC using special software Infrared Solutions FlexView 1.2.2 designed for this thermographic camera.

The results of the measurement were processed by Excel software and verified by statistical software Statistica 12 (ANOVA and TUKEY HSD Test).

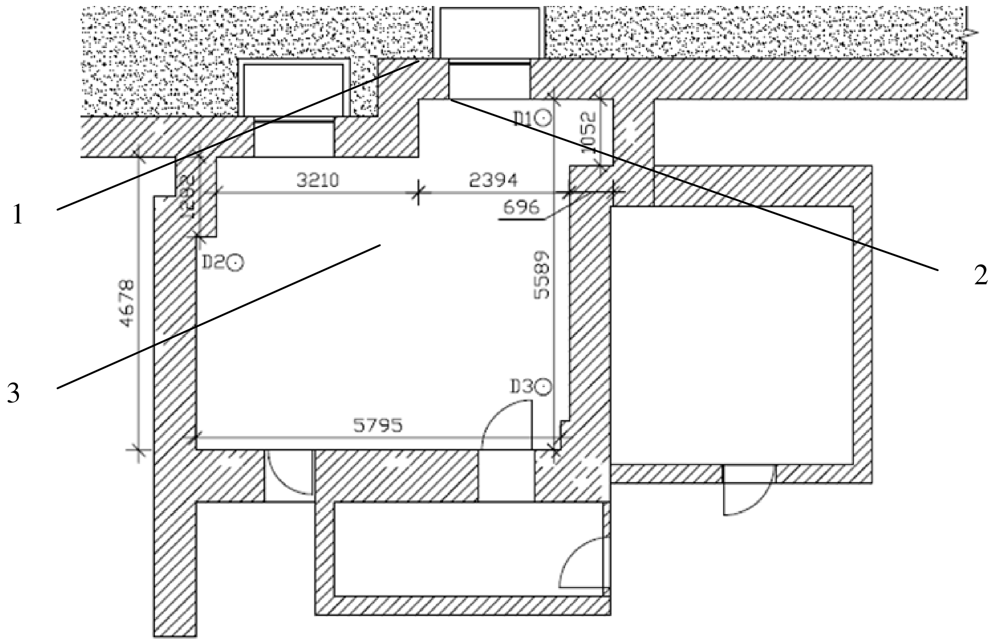

Fig. 1. **Subterranean basement room:** 1 – external wall; 2 – inside wet surface; 3 – room

Results and discussion

The results of long-term measurements of temperature and humidity at two locations in the room in the period before repairing of the walls are summarized in Table 2 and Table 3. The objective was to verify whether there are significant differences between the parts of the room that are closer or farther away from the moist walls.

Measurements were carried out in the middle of the room (dry area) and at a distance of 1 m from the damp walls (wet area). The measurement results shown in Table 3 are measured during normal weather without rain, the results presented in Table 4 are at the time of rainy weather.

The measurement results show that there are statistically significant differences in the air temperatures (lower by 7 %) and relative humidity (higher by 17 %) in the room, even during normal dry weather (Table 2). The difference is very important particularly during the rainy weather when the mean relative humidity difference between the central part and the wet part of the room near the walls is extremely high (Table 3), which shows the penetration of moisture from outside the soil into the poorly insulated outer wall of the room.

Table 2

Temperature and relative humidity of air before the improvement (without rain). Different letters (a, b) in the superscript are the sign of high significant difference (ANOVA; Tukey HSD Test; $p \leq 0.05$)

Place in the room	t ± SD, ºC	RH ± SD, %
Central part	21.2 ± 0.322^a	49.0 ± 1.502^a
Near the wet walls	19.7 ± 0.250^b	57.5 ± 1.998^b

SD – Standard deviation

Table 3

Temperature and relative humidity of air before the improvement (during rain). Different letters (a, b) in the superscript are the sign of high significant difference (ANOVA; Tukey HSD Test; $p \leq 0.05$)

Place in the room	t ± SD, ºC	RH ± SD, %
Central part	20.0 ± 0.419^a	52.8 ± 1.502^a
Near the wet walls	19.0 ± 0.429^b	76.3 ± 5.127^b

SD – Standard deviation

These results were further confirmed by measurement of surface humidity of the inner walls that are summarized in Table 4. From the results significant effect of rainy weather on the growth of the wall moisture is noticeable that is affected by direct or indirect contact from the wall that is in contact with the surrounding soil. In the period without rain, the average humidity of the walls was 36.43 %, during rainy weather it achieved 61.68 %.

Table 4

Average moisture of walls before the improvement (without rain and during rain)

Wall moisture	Without rain	With rain
Wall with the window, % ± SD	34.66 ± 11.65	63.86 ± 29.51
Wall on right from the window, % ± SD	43.09 ± 20.67	58.91 ± 29.86
Wall on left from the window, % ± SD	31.59 ± 15.01	61.28 ± 34.29
Average of walls, % ± SD	36.43 ± 12.96	61.68 ± 27.74

SD – Standard deviation

Photo and thermogram of the corner between two walls before reconstruction are given in Fig. 2. High humidity of some parts of the inner walls is also demonstrated at lower temperatures of these walls. The difference in temperatures of various parts of inner surfaces of the peripheral walls is visible on the thermogram.

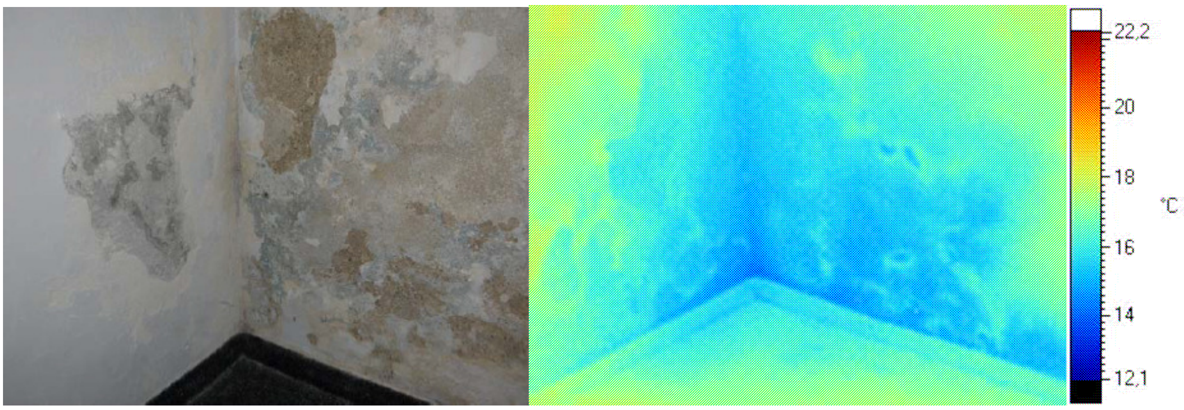

Fig. 2. **Photo and thermogram of the corner between the window wall and side wall**

Due to the bad microclimate inside the room there were arrangements made to reduce the influence of the outside wall on the indoor environment. With the aim to make the simplest solution and achieve the lowest cost the original interior plaster was removed and a new protective inner wall (thickness 70 mm) with a ventilated gap between the wet outside wall and the new inner wall was constructed. The results of temperature measurement and humidity in indoor environments after improvement are presented in Table 5.

The results show that there is considerably smaller difference between the temperature and humidity in the middle of the room and near the wall than it was before the modification. This difference is statistically significant, but it is possible to say that certain unevenness in indoor environment is in every room and lower temperatures together with higher relative humidity occur frequently. The difference is caused due to the colder exterior walls and it is not harmful. In comparison with the situation before the correction, this difference is much smaller.

Table 5

Temperature and relative humidity after the improvement. Different letters (a, b) in the superscript are the sign of high significant difference (ANOVA; Tukey HSD Test; $p \leq 0.05$)

Place in the room	t ± SD, ºC	RH ± SD, %
Central part	20.2 ± 0.152^{a}	45.3 ± 0.543^{a}
Near the wet walls	19.1 ± 0.117^{b}	51.4 ± 0.521^{b}

SD – Standard deviation

The results of measurement of moisture of the walls after reconstruction are shown in Table 6. Average moisture of the walls after the improvement was only 8.43 %. The difference between moisture of the original walls before the reconstruction (Table 4), and after improvement (Table 6) is very significant and confirms the proper function of corrective remediation structures made in the room.

Table 6

Average moisture of walls after the improvement.

Wall moisture	Without rain
Wall with the window, % ± SD	8.17 ± 2.44
Wall on right from the window, % ± SD	8.10 ± 1.90
Wall on left from the window, % ± SD	9.04 ± 2.40
Average of walls, % ± SD	8.43 ± 1.75

SD – Standard deviation

Conclusions

1. The measurement results show that it is possible by measuring the temperature and humidity to identify the sources of problems causing high humidity.
2. The infrared thermography is a useful method for determination of changes in the walls, which cannot be identified visually.
3. The method, which effectively reduces the effect of moisture of walls on indoor environment that is not very expensive and can be done by yourself, is removal of the old plaster and construction of new interior walls (brick wall 70 mm) with a ventilation gap (40 mm).
4. The measurements show that the described method used to avoid the effects of moisture of walls on the indoor environment is effective. Improvements implemented for the reduction of moisture really reduced the wall moisture from 36.4 % to 8.4 %, which reduced the air humidity near the walls from 76.3 % to 51.4 %.
5. This type of room improvement can be recommended for similar cases of reconstruction in basement rooms that are not used for living.

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