The Influence of Building Materials on Relative Humidity of Internal Microclimate

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Abstract. Sustainable building covers wide range of criteria including environmental, social and economy issues. Relative humidity of the internal environment belongs to the group of social criteria dealing with the quality of indoor microclimate and is one of the important indicators. Low humidity level can cause dry skin, throats and nasal passages and can cause annoying static electric sparks. High humidity level can lead to growth of moulds and bacteria and can cause condensation problems on the cold surfaces. Appropriate level of relative humidity can be operate by building service systems which increases operating energy in buildings and is sensitive to correct set up, control and monitoring. Relative humidity can be also influenced by the choice of building structures and structural materials without any operating energy. The paper summarizes latest research on the influence of relative humidity on health hazards and influence of building structures and structural materials on the relative humidity.

1. Quality of indoor microclimate in buildings
Modern people spend most of their time in buildings. Many surveys show [16] that nowadays people spend almost 90% of the time in the buildings – in residential buildings, offices, schools, day-care centres and other building facilities.

Figure 1. Time spend in buildings. [16]
For this reason, it is essential to focus on the quality of the internal environment. This also means if they are unwell, they will suffer symptoms and discomfort while indoors, only some of which may be related to the buildings they occupy.

1.1. Sick Building Syndrome

Technical term describing the situation where people in buildings suffer from symptoms of illness or feel unwell for no apparent reason is described as Sick Building Syndrome (SBS). Symptoms often get worse with time when people spend time in buildings and improve or disappear when people are out of the building.

SBS leads not only to serious civilization illnesses but also to social economy problems. Job performance is compromised, productivity loss is significant. It causes reduced work performance and increased absenteeism, resulting in a total cost which may well be in the range of 0.5–1.0 % of GNP [1]. In extreme cases, the personal relationships of building users may also be compromised.

The sick building syndrome is widespread and may occur in all types of buildings – residential and office buildings, schools etc. SBS problems are estimated at up to 30% of new, rebuilt or refurbished buildings. The most common SBS symptoms are the following [1]:

- Neurotic effects – lethargy, headaches, fatigue, lack of concentration, irritability, enhanced or abnormal odour perception.
- Mucous-membrane irritation – throat and nose irritation, cough, shortness of breath, stuffy nose, dry throat, runny or blocked nose (sometimes described as congestion, nosebleeds, itchy or stuffy nose), dry or sore throat (sometimes described as irritation, upper airway irritation or difficulty swallowing).
- Asthma and asthma-like symptoms – difficulty in breathing, wheezing and chest tightness.
- Irritated, dry or watering eyes (sometimes described as itching, tiredness, redness, burning or difficulty wearing contact lenses),
- Skin symptoms – dryness, pruritus, rash, itching or irritation of the skin, occasionally with a rash, less specific symptoms such as headache, lethargy, irritability and poor concentration.
- Flu-like symptoms.

Typically several of these symptoms are experienced simultaneously and they are often accompanied by complaints about stuffiness, poor air, dry air, noise, light or temperatures which are too hot or too cold. The severity of these symptoms and their frequency depend on the quality of the design of the building, the indoor environment and the equipment.

![Figure 2. Dependence of quality of internal microclimate on relative humidity and internal temperature (source: Centre of passive buildings, www.pasivnidomy.cz).](image-url)
The SBS causes have been recognized in connection with inappropriate building design, influence of materials used in buildings and furniture, interior equipment as copiers, computers etc. insufficient air exchange and ventilation and high concentration of CO₂, VOC etc. The quality of indoor environment most affects these parameters [4]:

- Unsuitable lighting, colour temperature etc.
- Unsuitable heating – too high indoor temperature, dry air. The influence of relative humidity on the overall quality of internal microclimate is obvious (Figure 2.).
- Bad acoustic.
- Unsuitable air exchange and ventilation – microbes and mites in air-handling units, toxic moulds, chemical and biological pollution, accumulation of potentially dangerous gases.

1.2. Relative humidity in buildings

The relative humidity is the ratio between the instantaneous amount of vapour in the air and the vapour content of the air at the same pressure and temperature at full saturation. The amount of water vapour in the interior is determined by the condition of the water vapour in the exterior, the way of ventilation and the source of water vapour in the building.

In summer period, the content of water vapour in the outdoor air is high. Once the air is brought into the interior and cooled, the resulting air is damp and the RH can rise above 70%. On the contrary, in the winter, there is a small amount of water vapour in the outdoor air. After the air is brought into the interior and heated (without further adjustment), the resulting air is dry and the RH may fall below 30%.

Sufficient level of indoor relative humidity is 40 – 70% RH [3]. When RH reach over 70%, water vapour may condense on cooler surfaces and moulds can grow on almost any surface.

With relative humidity below 30%, people often suffer from drying out. The airway mucosa is dried, and dust, dirt and disease can not be quickly removed from the airways. Longer breathing of the respiratory tract increases the risk of respiratory tract illness. Typical consequences of this process are cough, bronchitis, runny nose and sinusitis. The plastics are electrically charged and collect additional dust particles in the case of dry air. Dry skin and eyes are also a frequent consequence of low RH. [3]

Conditioning of relative humidity in air-conditioning units is energy and cost-consuming. The source of water vapour in the interior are for example: showering (2600 g/h), cooking (1500 g/h), drying clothes (200 g/h), flowers (15 g/h), occupant (30–200 g/h) [3]. Relative humidity can be also regulated by the choice of building structures and structural materials without any operating energy due to sorption properties of building materials.

2. Sorption

The dependence of equilibrium moisture on the relative air humidity at constant temperature is called a sorption isotherm. Sorption theory attempts to describe and explain the sorption process in hygroscopic materials. Hygroscopicity is the ability of materials to easily absorb, desorb and maintain moisture from surrounding environment. Exposing an absolutely dry material to a constant temperature environment and air saturated with water vapour, the material starts to bond water by a process called adsorption, the reverse action is called desorption.

2.1. Sorption isotherm

The ability and potential of adsorption and desorption of each material is defined by sorption isotherm, which is a curve that presents the amount of absorbed/desorbed water vapour in the material at given relative humidity. It depends on pressure and temperature.

The sorption curve is hysterical, adsorption does not correspond to desorption. Part of the moisture remains accumulated in the material. The shape of the sorption isotherm differs according to material type and according to different vapours and gases. Typical unrestricted monolayer-multilayer shape of sorption isotherm for building materials is shown in Fig. 3. The magnitude of the sorption hysteresis is expressed by the ratio RVDadsorption/RVDdesorption. The sorption isotherm ratio for adsorption and desorption for the relative air humidity range φ = 20–90% is relatively constant and varies depending
on the type of material. At $\varphi < 20\%$ and $\varphi > 90\%$ sorption hysteresis approaches one and the difference between adsorption and desorption is lost.

![Figure 3. Typical adsorption and desorption curve of building materials. [15]](image)

Figure 4 shows sorption isotherms of four different types of clay materials compared to other building materials. Measurements have been performed at the FEB Laboratory in Kassel [5]. The results clearly show that the higher amount of clay minerals in the clay materials the higher absorption capacity of the materials is expected. This is further influenced by the content of various types of clayey minerals.

![Figure 4. Comparison of sorption isotherms for typical building materials. [5]](image)

### 3. Moisture buffering in building structures

One of the main goals of advanced building concepts based on principles of sustainable building is to achieve highest quality of internal microclimate by minimizing of energy consumption both in operating and in building up phase. So called “environmental active” materials can help to avoid using energy demanding devices and to reduce operating energy for stabilization of internal microclimate. Passive systems for keeping specific thermal and humidity conditions are very well known from historical building – they are several examples of historical sandstone cellars and cornlofts, wine cellars from adobe bricks etc.
3.1. Measurement methods of sorption potential of building structures

To compare sorption potentials of single building materials sorption test according to the European Standard EN ISO 12571:20134 is recommended. Sorption curve of the tested material which describes the potential to accumulate air humidity is the result of the experiment and can be compared to other single material. The formula of sorption curve can be used for further mathematical simulations. The main disadvantage of this kind of test is that it doesn’t say anything about the real building structure which typically consists of several materials in several layers.

Several experimental methods trying to describe the influence of building materials on indoor relative humidity have been introduced. Some of them have been proposed by Time (1998), Padfield (1999), Hansen et al (2000) etc. Simonson et al (2002) gives an example how wooden based structures can significantly reduce the peak of indoor humidity (by as much as 35 %) and increase indoor humidity (up to 15 %). Full scale measurement of moisture buffering in building materials have been carried out by Mitamura et al (2001). Rode (2005) within the NORDTEST project proposes a test protocol for experimental determination of the moisture buffer value. The test protocol proposes climatic exposure which vary in 8 h + 16 h cycles: 8 h of high humidity and 16 h of low humidity. The reason comes from usual daily cycle which is 8 h as sleeping time, working hours etc. and also from practical reasons during the test. The low humidity is proposed 33% RH and the high level 75% RH, however other humidity levels are proposed according to saturated salt solutions. Also the size of test specimens is recommended so the minimum of exposed surface area is 0.01 m2 and the thickness should be at least the moisture penetration depth for daily humidity variations or 10 mm. A minimum 3 cycle test have to be carried out. This test also describes sorption properties of single materials.

An interesting full scale test of moisture buffer capacity of walls of the surface area of approx. 15.38 till 20.24 m2 was carried out by Mortensen et al (2005). Plasterboard construction and cellular concrete wall were tested. The idea was to mimic the exposure of moisture variations to interior surface materials. To measure moisture buffering effect of the structures the room was subjected to controlled moisture variations. The results proved that moisture buffer capacity of materials can be used to reduce humidity variations of the indoor environment.

3.2. Dynamic sorption tests

Full scale test of dynamic sorption for building structures has been developed and tested by Ruzicka, Divis (2016). The main idea of dynamic sorption test is to simulate real situations in the building and behaviour of real building structures in “real” conditions. The proposed test protocol for climatic chamber is based on following situations: internal environment and tested structure is in equilibrium state, than the internal environment is facing intensive increase of relative humidity for a specific period. After that 2 scenarios are possible: (i) at the end of high humidity period it is observed how relative humidity in the climatic chamber decreases which determines the potential of tested building structure to moderate the moisture peaks and to absorb the moisture from the environment (adsorption potential) or (ii) the climatic chamber is ventilated to the reach the starting level of internal humidity and it is observed how much moisture is absorbed in the structure it means how the internal humidity in the chamber increases (desorption potential).

The proposed test simulates the following situations in the building:

- internal environment is in equilibrium state, there is 23 °C and relative humidity 45 %,
- internal environment is facing intensive increase of relative humidity, RH up to 95 % RH for specific period 60 minutes, the temperature is constant (in real situation someone is taking shower, cooking etc.).

After step 2. following scenarios are possible:

- VAR I: At the end of the high humidity period the room is ventilated for specific time period (20 minutes) to the reach the starting level of internal humidity (RH 45 %) and it is observed how much moisture is absorbed in the structure it means how the internal humidity increases – desorption potential of the building structure (Figure 5 left).
• VAR II: At the end of the high humidity period it is observed how relative humidity in the room decreases which determines the potential of tested building structure to moderate the moisture peaks and to absorb the moisture from the environment – adsorption potential of the building structure (Figure 5 right).

3.3. Preliminary full scale tests of dynamic adsorption/desorption

The aim of preliminary tests was to prove the proposed testing methodology and to prove different behaviour of test samples. Dynamic sorption properties of real structural parts have been carried out at UCEEB CVUT in Prague. Following test specimens of the size 820 x 750 mm were tested in the climatic chamber:

• Fair-face brickwork from unburned clay hollow blocks Heluz Nature Energy 12/25 of the thickness 120 mm,
• Unburned clay hollow blocks Heluz Nature Energy 12/25 of the thickness 120 mm with clay plaster PICASS ECONOM 22 mm,
• Ceramic hollow blocks Heluz 8 80 mm with lime plaster HASIT 160 Fein Kalkputz.

Dynamic desorption test (Figure 7 left): This part of the test describes the behaviour of the test sample after the high humidity period finishes and relative humidity in the environment drops down to starting moisture level for example due to ventilation, open windows etc. The ability of tested structure to accumulate moisture in a short time period and to increase relative humidity gradually in the environment is observed. The test consisted of following steps (compare to Figure 5 right): 1. conditioning of the test sample at 45 ± 1 % RH for 48 hours, 2. high level of humidity at 95 ± 1 % RH for 60 minutes, 3. ventilation of the environment to the starting humidity level 45 ± 3 % RH for 20 minutes, 4. monitoring of RH changes in the climatic chamber for 16 hours.
Dynamic adsorption test (Figure 7 left): This situation describes the behaviour of the test sample after the high humidity period finishes and moisture from the environment is accumulated to the tested wall. The test consisted of following steps (compare to Figure 5 left): 1. conditioning of the test sample at 45 ± 1 % RH for 48 hours, 2. high level of humidity at 95 ± 1 % RH for 60 minutes, 3. monitoring of RH changes in the climatic chamber for 16 hours.

Differences in behaviour of test samples regarding the ability to absorb humidity and to decrease the peak are obvious. As expected uncovered unburned blocks have the highest potential and the ceramic blocks with lime plaster the lowest.

4. Passive moisture buffering in modern building structures
The principles of passive moisture buffering have been used in many examples. Natural clays in form of clay plasters, clay boards, unburned bricks or rammed earth structures are used to keep appropriate level of relative humidity in internal environment. One of shining examples is the Ricola Herb Centre in Laufen by Basel, Switzerland (Herzog & de Meuron, 2013). The façade consists of prefabricated rammed earth panels. In the stocking part earthen panels keep the stable microclimate for storing of herbs without any other ventilation system which decreases the energy demand in operation phase of the building, makes it energy efficient and decreases negative environmental impact. The range of use is great as the building dimensions are approx. 50 x 30 m with almost 10 m height.

5. Conclusion
The methodology for dynamic sorption tests developed within the project was found sufficient to assess different structures and provides valuable results. High potential of natural porous materials as natural clays in form of clay plasters, clay boards, unburned bricks or rammed for moisture buffering was proved by preliminary tests and research in this field will continue. Principals of passive moisture buffering can
be used for modern sustainable construction to help to keep the quality of internal microclimate regarding appropriate level of relative humidity without any operating energy and can effectively reduce operating costs.

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