Building Simulation 2003

Eighth International IBPSA Conference
Eindhoven, Netherlands
August 11-14, 2003

INDOOR AIR HUMIDITY VARIATIONS AND ITS EFFECTS ON THE MOISTURE PERFORMANCE OF BUILDING ENVELOPE

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ABSTRACT

With the current enhancements moisture engineering analysis of building envelope structures becomes a critical design element. Building envelopes design is often modeled using advanced hygrothermal models and customized for particular interior and exterior environmental loads. This is always conducted by assuming interior environmental conditions that are decoupled by the contributions of the envelope itself. This paper presents the results of whole building hygrothermal simulations, its effects on the indoor air conditions and on the building envelope. The hygrothermal performance of two different rooms with the same thermal and moisture loads is presented. The results show that materials with hygroscopic capacity have the ability to improve the performance of building envelope structures even to such level that condensation and mold growth conditions are eliminated. A state of the art hygrothermal modeling analysis is used to quantitatively assess the performance of both hygroscopic capacity and indoor inhabitant moisture generation.

INTRODUCTION

Indoor air humidity is controlled by the interior moisture loads, ventilation, and according to recent studies by the hygroscopic moisture capacity in interaction with the indoor climate. Hygroscopic materials in the envelope, have been shown to limit the variations in indoor air humidity during intermittent loads. They tend to store moisture from the air and release when dry air is introduced. This has been estimated to improve comfort and acceptability of indoor air. Building envelope parts, even when well insulated, have areas that may have low interior surface temperatures. Reasons for these low temperatures - often in joints and corners - can be e.g., local thermal bridges, air leakage paths (infiltration) or additional interior resistance for heat flow caused by furniture. The relative humidity on the interior surface of the envelope and its hourly behavior depends on the conditions in indoor air and the properties of the material in question. High humidity in indoor air may result in even higher humidity causing the 'cold spots' of building envelope. In many situations the water vapor of the indoor air can condense in liquid form when in contact with a cold spot. In most instances, it is difficult to directly detect these cold spots in terms of localized higher relative humidity and water contents, but by their effect such as the darker ghost marks left by dust and higher water contents at the surfaces. Hygroscopic interior surface materials can lower the maximum moisture contents in indoor air and at the same time absorb moisture from the surface without allowing the relative humidity to increase to harmful levels.

Quite a few papers on the use of the building envelope as a critical buffer element for both thermal and moisture control have been published (e.g., Salonvaara et al., Simonson et al., Rode et al., Padfield), but only few of them investigate at the same time the performance of the building envelope. To investigate the influence of the building envelope on the interior moisture load, a wholistic building approach is required. In this wholistic approach all critical elements of the building (roofs, walls and floors) are needed. The contributions of each of these components must be coupled to the occupant thermal and moisture production activities, mechanical systems operation or code regulatory requirements.

In this paper the authors have conducted a preliminary assessment of how the coupling of the building envelope influences the interior moisture levels in building. The objective of the study was to quantify the influence of the moisture contributions of the coupling of the building envelope and the interior environment. Additional attention has been paid on the performance of building details such as thermal bridges that may exist in many locations of the building envelope.

SIMULATIONS

Hygrothermal simulation model LATENITE was used for the simulations of this paper. The model is primarily used for simulating multi-dimensional building envelope details but it is also capable of simulating the indoor climate in interaction with the building envelope. The model is explained in more details in ASTM Manual 40 (2001). A series of simulation were performed on a building located in Helsinki, Finland. The analysis focused on a west-facing bedroom that was surrounded by identical constructed wall systems for all four orientations and sides of the building. The four exterior walls, the interior partition wall, floor and ceiling were all assumed to have impermeable and adiabatic boundary conditions at the two sides.

Two separate sets of simulations were carried out for the study. In the first series, the behavior of indoor air humidity was simulated using a whole building simulation model for one zone (the room). In the second series the effects of indoor air humidity and it's variations on the building envelope parts were parametrically investigated. In the whole building simulations activity the building envelope parts were simplified to 1-dimensional surfaces with the appropriate sizing of the significant surface areas. The building details with smaller surface areas and with the corresponding less effect on the indoor air conditions were investigated and simulated with known indoor conditions from the first whole building simulations.

The main features of the bedroom as well as the heating, cooling and ventilation of the bedroom are listed below.

The bedroom is assumed to be in an apartment building where the surrounding rooms have the same temperature and vapor pressure as the investigated room.

The following geometry, materials and climates have been selected:

- 12 m^2 floor area, 2 occupants for 9 hours each night
- outdoor ventilation rate (0.5 ach).

The room is 4 m x 3 m x 2.7 m and the west-facing external wall is 3 m long. The external and internal walls had the same construction. The ceiling is active in moisture transfer with the indoor air, but the floor is not active because it is coated with a non-permeable coating. The external wall has a 1.2 m x 1.5 m triple-pane window with a closed venetian blind, which transmits 25% of the solar radiation striking the window. For simplicity, it is assumed that the solar radiation is evenly distributed over all the internal surfaces. The building is located in an open terrain and the absorption coefficient for the external wall is 0.8. The ventilation rate is 0.5 ach, which corresponds to 4.5 L/s. Climate of Helsinki, Finland, was selected for exterior conditions.

Materials in the walls from interior to exterior:

- Interior surface: vapor open paint or vapor retarder paint
- Interior board porous wood fiber board
- Building paper
- Insulation: cellulose fiber insulation.

The indoor temperature is at least 20°C during the heating season, where the heating season is chosen to be from October 1st till May 31 in Finland.

In Figure 1 the exterior climatic conditions are plotted out for the temperature and the relative humidity.

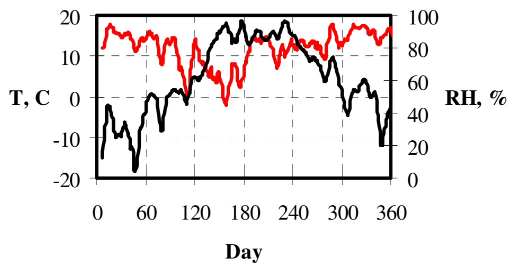

Figure 1: Seven day running average Relative Humidity and Temperature in Helsinki, Finland. Day starts from the beginning of the year.

From the climatic information presented in Figure 1 it can be noted that the most humid periods of the year occur during the fall and winter. The critical time of year for many indoor air humidity problems is often during the autumn (high humidity) whereas the building envelope experiences typically more problems during the cold season or right after it when exterior temperature increases above freezing.

ANALYSIS OF INDOOR CONDITIONS OF HYGROSCOPIC AND NON-HYGROSCOPIC ROOM

First the results from the whole building (room) simulations are presented for when the room has hygroscopic mass on the building envelope dampening indoor humidity conditions or when the interior surfaces of the building envelope are vapor tight and no mass transfer exists to and from indoor air.

In Figure 2 the simulated indoor air relative humidity is plotted as a function of temperature and moisture ratio of air for all the hours during a full year for a room with hygroscopic mass (vapor open surfaces in building envelope) and for a room with vapor tight interior surfaces. In Figure 3 the same results are shown as a function of time.

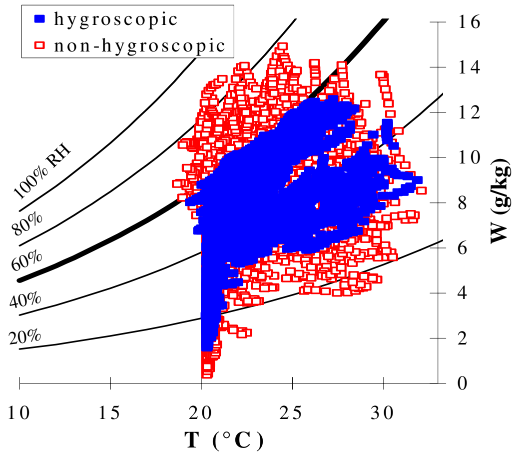

Figure 2. Hourly values of indoor temperature and humidity during the entire year in the hygroscopic case and non-hygroscopic case in Helsinki, Finland.

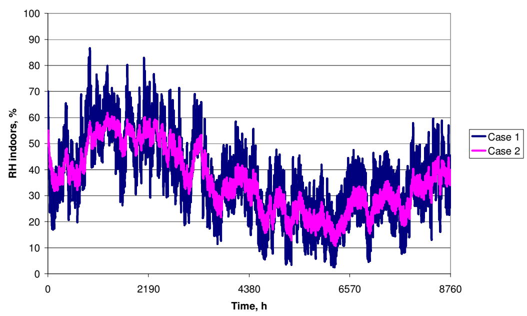

Figure 3. Indoor air relative humidity during the entire year in the hygroscopic case (2) and non-hygroscopic case (1) in Helsinki, Finland.

Then these simulation results of indoor air humidity are used for a 2D-thermal bridge situation (temperature ratio of interior surface f=0,63). These simulations have been carried out separately with a heat and moisture transport model using the resulting indoor conditions as known boundary conditions for the structural model. Surface areas of thermal bridges are small compared to the plain wall surface area and the assumption has been made here that the thermal bridges and their moisture performance has little effect on the indoor air conditions. When simulating the indoor air conditions in the whole building simulation model only the plain wall areas without thermal bridges were taken into account.

EFFECTS OF INDOOR AIR HUMIDITY ON BUILDING ENVELOPE

The hygrothermal performance of building envelope systems (walls, roofs & floors) exposed to outdoor climate are affected by the initial moisture content, intentional and unintentional moisture leaks, diffusion of indoor air and air infiltration/exfiltration between indoor air and the structure. In order to minimize the moisture flow from indoors to the structures an adequate vapor resistance and air tightness should exist in the interior side of the envelope structure. The consensus in Nordic countries is that a ratio 5:1 has been selected as an appropriate value for the ratio between the interior layers of the insulation and exterior layers, i.e., the layers on the interior side of the insulation layer should have a vapor resistance 5 time that of the layers on the exterior side of the insulation layer.

When a building envelope designer attempts to make use of the hygroscopic mass in the building envelope one needs to avoid vapor tight interior surfaces. Open interior surface (in terms of vapor diffusion) allows for fast drying of the envelope structure towards the interior in the warm weather conditions but may also create a risk for moisture accumulation in the cold weather periods. However, it has to be mentioned here, in order to have a hygroscopically active building envelope, we do not need to avoid the use of a vapor retarder. The only requirement is that the selection of the placement of the vapor retarder needs to be selected wisely.

To investigate the effectiveness of hygroscopic mass, a selected number of vapor open structures have been analyzed. Two parameters were investigated; the vapor resistance and thermal resistance of interior and exterior wall boards.

Short-term variations (hourly) of humidity in indoor air was found to mainly affect only the performance of the interior surface and possibly a few millimeters beneath the surface of wallboards. Materials layers closer to the outdoor air were found to be affected by the daily average humidity in indoor air. In other words, if the hygroscopic mass only changes the hourly behavior of indoor humidity but not the average humidity over the whole day, then the moisture performance of the whole wall was found not be much different. The only significant difference was found in the layer closest to the indoor air.

HOURLY VARIATIONS OF INDOOR HUMIDITY AND EFFECTS AT THERMAL BRIDGES

Large hourly variations in indoor air may affect the thermal bridges and the localized moisture conditions to a level that even condensation may exist at times. The surface temperature near corners, window sills and floor/wall details may have such low temperatures that they are below the dew point of indoor air and the resulting surface temperature would end up above the critical humidity for mold growth.

The probable conditions on the surfaces of thermal bridges were analyzed with the help of temperature ratio, which is defined in this paper as:

$$F = (T_s-T_o)/(T_i-T_o)$$

where T_s is the surface temperature, T_i is indoor air temperature and T_o is the outdoor air temperature. In steady-state conditions the temperatures on the surfaces of and inside the building structure vary when the temperature differential across the detail varies, whereas the temperature ratio remains (approximately) the same. Lowest temperature ratio of the interior surface can be considered as a performance index of the structure. Typically the temperature ratio is determined via a thermal bridge analysis.

This relative temperature factor can be used in estimating the surface temperature at the thermal bridge at different outdoor air temperatures. Thermal mass effects are not taken into account in this factor and for this reason it is only an estimation of the actual surface temperature. If the surface temperature becomes lower than the dew point temperature of indoor air condensation may occur on the surface. In the middle of the winter during cold outdoor weather temperatures close to 0ºC have been found in corners even in well insulated buildings.

THERMAL BRIDGES WITH VAPOUR TIGHT INTERIOR SURFACE

The relative humidity conditions on the surface of a thermal bridge is presented in Figure 4 for two different rooms with same thermal bridges. The surfaces of the thermal bridges were assumed to be vapor tight in these cases. The differences between the rooms are in the hygroscopic capacity. Case 1 is a non-hygroscopic room and case 2 is a room with high hygroscopic mass on the walls. Relative temperature factor for the thermal bridge was 0.63.

In case 1 even condensation occurs in the middle of the winter on the surface of the thermal bridge. Relative humidity is above 80% for 7.6% of the time i.e., for almost one month every year. In case 2 the relative humidity on the interior surface of the thermal bridge never exceeds 80%.

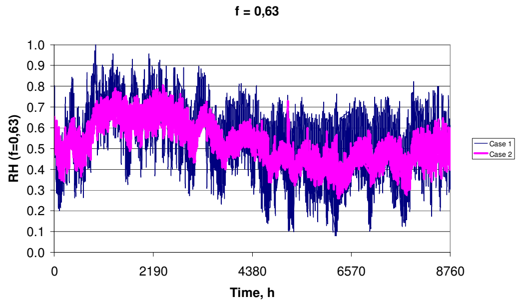

Figure 4. Relative humidity on the interior surface of a thermal bridge with relative temperature factor 0.63 during one full year. Interior conditions in a room with or without hygrothermal mass. Starting date is June 1st. Dark line is for the non-hygroscopic case and light line for the hygroscopic case.

In Figure 5 the same values are presented in a cumulative curve over a full year. It can be clearly seen how hygroscopic mass can cut the maximum and minimum humidities on the surfaces of thermal bridges as well as in indoor air (Figure 3).

Condensation and high relative humidity may be experienced on the vapor tight surfaces with low temperature during the times when indoor humidity increases to its maximum of the day due to interior moisture sources. But what happens on the surfaces of the interior wallboard when the material can absorb moisture?

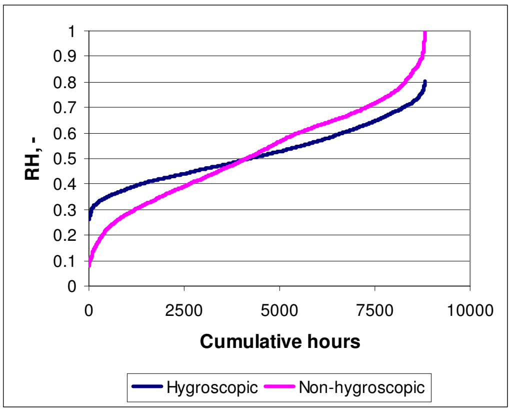

Figure 5. Cumulative distribution of relative humidity on the thermal bridge surface in rooms with or without hygroscopic mass interacting with indoor air.

When using the temperature ratio that does not taken into account the thermal mass of the building envelope the extreme conditions with surface condensation or high humidity on the surface of the thermal bridges with vapor tight interior surface existed only for a few hours per day i.e., the surface experienced also large variations in humidity on hourly basis. This situation can be representative e.g., on a window surface. In those cases there was no moisture storage on the surface and thus no moisture accumulation even for a shorter time unless there was real surface condensation. In the simulated room there wasn't really much time for condensation. When longer periods of condensation conditions exist it is possible that there is enough moisture accumulation during the condensing hours that the condensed moisture has not enough time to evaporate back to the indoor air from the surface. This might lead to longer and extended periods of high humidity on the surface and materials beneath. This could result in mold growth, structural or esthetical damage on the surface.

THERMAL BRIDGES WITH VAPOUR PERMEABLE SURFACE

A 2-dimensional thermal bridge was simulated with the known indoor conditions from whole building simulations. Two interior conditions were used: those from the simulations for the room without hygroscopic mass in the walls (vapor tight surfaces) and those for the room with hygroscopic mass on the walls and the ceiling. The conditions in these two rooms are on average approximately the same but hourly variations are very different. The room without hygroscopic mass has very large variations in indoor humidity on hourly basis due to intermittent occupancy in the room. However, the daily average humidity is very close to the same as for the room with dampened humidity variations.

A thermal bridge on a wall with the lowest temperature ratio of 0.63 was analyzed. The analyzed wall structure had a 13 mm gypsum board as the interior wall board and a polyethylene vapor retarder beneath it. The wallboard was painted with a permeable paint (vapor diffusion thickness for the paint was d = 0.1 m).

ANALYSIS

The relative humidity at the location of the thermal bridge where the lowest temperature was found on the wall surface (center of thermal bridge) was recorded on both sides of the gypsum board. Gypsum board is slightly hygroscopic but not as much as the porous wood fibreboard that was used in the plain wall areas in the whole building simulation.

The long-term average humidity in the room is approximately the same and independent whether the wall surfaces are vapor permeable or not because the walls employed a vapor retarder and no differences existed between the moisture fluxes through the walls. However, when looking at the results for the building envelope (Figure 6) we see quite large differences in the courses of local spots in the wall, in this case on the exterior and interior surfaces of gypsum wallboard that located at the thermal bridge.

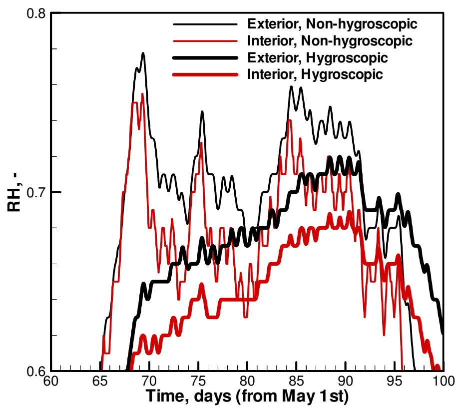

Figure 6. Relative humidity on the interior and exterior layers of gypsum wallboard placed on top of a thermal bridge. Indoor air conditions are either with hygroscopic mass or without hygroscopic mass.

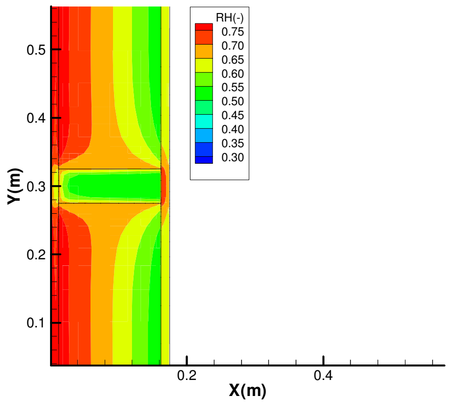

Figure 7. Relative humidity distribution in the thermal bridge detail 70 days from the beginning of the simulation (starting date May 1st). Exterior conditions are on the left and indoor air on the right.

A contour plot of relative humidity in the wall section is presented in Figure 7. A clear effect of thermal bridge on the local humidity conditions can be seen around the thermal bridge (at location y = 0.3 m).

When the indoor air had large variations in indoor humidity (no hygroscopic mass in the room) the building envelope experiences higher humidity in the gypsum board. There might be several reasons for this. First, the moisture transport coefficients are not constants but rather functions of relative humidity and at higher humidity the materials (including paints) typically are more vapor permeable. Second, small temperature differences exist in the wall because of latent heat effects and this may affect the wall behavior. In this wall the temperature differences in the wallboard between different cases was found to be quite small and in the order of less than 0.5 K. Large variations can however exist in the wall structures during ‚shoulder' seasons e.g., in the fall when exterior climate is rapidly becoming colder and the parts of building envelope with hygroscopic mass take a substantially longer time to balance out to the new climatic conditions resulting in continuously lower indoor humidity in the hygroscopic case because of continuous mass flow to the absorbing materials.

CONCLUSIONS

Hygroscopic mass inside a building including the building envelope (walls, ceiling, floor) can have a strong effect on the time wise behavior of the indoor air. The differences are more pronounced when the ventilation rate is small compared to the moisture loads indoors. Mass transfer between indoor air and the moisture absorbing materials can dampen the variations in indoor air significantly. The higher humidity in the case without hygroscopic mass in indoor air poses a risk for the building envelope especially at the location of thermal abnormalities e.g., thermal bridges. High indoor humidity may result in surface condensation if the temperature of the surface is below the dew point temperature of indoor humidity. By lowering the variations of indoor humidity with the use of hygroscopic mass in the room the risk of condensation can be lowered substantially.

The hourly variations in indoor air have been shown in previous studies not to penetrate deep into the wall structure. That means that typically only a few millimeters of the wall surface sees the hourly amplitude of indoor humidity and other parts inside the wall only react to longer term changing in indoor humidity. Therefore, the instantaneous changes in indoor air humidity are of interest in terms of interior surfaces and their hygrothermal behavior only. These are however the surfaces that have the most effects on the indoor air quality, and detrimental effects such as mold growth conditions are unacceptable in the surfaces next to indoor air or on the interior wallboard.

Currently the whole building simulation models very rarely take into account multidimensional building details. The indoor air conditions are mainly affected by the building envelope parts with larger area and thus little advantage can be expected even if the details with specific flaws or of special interest would be modeled. However, even if the critical details in the building envelope parts did not have much effect on the indoor air, the resulting changes in indoor air may have a strong effect on the building details. These can be analyzed in more detail with the known boundary conditions from whole building simulation tools.

ACKNOWLEDGEMENTS

This work was carried out as part of an on-going larger project investigating the effects of hygroscopic mass on the indoor air quality „Improving indoor climate with wooden structures". The financial support of National Technology Agency (Tekes), Wood Focus Ltd. and other participating companies in the project is greatly appreciated.

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NOMENCLATURE

F Temperature factor, $(T_s-T_o)/(T_i-T_o)$

RH Relative humidity, - or %

T_s Interior surface temperature, °C

T_o Outdoor temperature, °C

T_i Indoor temperature, °C