Full-Scale Experimental Investigation of Moisture Buffering Effect and Indoor Moisture Distribution

X. Yang **S. Vera** **J. Rao, PhD** **H. Ge, PhD** *Member ASHRAE* **P. Fazio, PhD**

ABSTRACT

Indoor humidity is a very important factor influencing indoor air quality, thermal comfort, energy consumption, and building envelope performance. Moisture buffering effect is considered as an efficient factor in moderating the indoor humidity level.

In this study a full-scale two-storey wood-framed test-hut is built inside an environmental chamber to investigate the moisture buffering effect. The parameters studied include two different interior surfacing materials (gypsum board and wooden panels), different ventilation rates (0.3, 0.5, 0.75 and 1.0 ACH), and moisture generation rates of 2.3, 4.6, and 9.2 g/m^3·hr (1.05, 2.01, and 4.02 grain/ft^3.hr). A new methodology is used to evaluate moisture buffering based on the calculation of the amount of moisture absorbed/released by the surface materials.

This paper presents the experimental design and the preliminary results for uncoated gypsum board at 0.5 ACH with moisture generation rate of 4.6 g/m^3·h (2.01 grain/ft^3.hr). The results show that gypsum can absorb as much as 9.9 g/m^2 (14.19grain/ft^2) moisture in one day cycle; additionally, the relative humidity across the room shows differences of up to 15% RH among different locations.

INTRODUCTION

Moisture Buffering Effect

Hygroscopic materials, such as indoor finishings and furnishing, have the ability to moderate indoor relative humidity (RH) in buildings. These materials absorb moisture when indoor RH is high and release it when the air is drier. This is known as moisture buffering effect. Since one third of moisture generated inside rooms could be absorbed by hygroscopic materials (Tsuchiya 1980), indoor RH can be controlled passively. Therefore, moisture buffering could help not only to improve the indoor environment, but also to reduce energy consumption, condensation, and mold growth.

Several works have focused on evaluating the moisture buffering capacity of different indoor surface materials by means of its effect on the variation of relative humidity. Experiments were performed inside full-scale test-rooms (Rode et al. 2001; Salonvaara et al. 2004; Hedegaard et al. 2005a) and inside field test-houses (Simonson et al. 2004). Since these tests were carried out under well-mixed air conditions, the indoor conditions of relative humidity and temperature were measured by one or only few sensors at the center of the test rooms. However, temperature stratification and uneven moisture distribution are the prevalent conditions within rooms. Moreover the distribution of RH can vary significantly along interior surfaces, which affects the moisture transfer between the indoor air-film and the surface material, and as a result, the moisture buffer behavior of surface materials (Hedegaard et al. 2005b).

Although, several finishing materials, such as gypsum plaster, gypsum board and wood fiberboard with or without painting (Mitamura et al. 2004; Ramos and Peixoto de Freitas 2004; Ojanen and Salonvaara 2004; Rode et al. 2004; Ojanen and Salonvaara 2004), have been tested in terms of their effect on moderating the indoor RH, there is lack of experimental data on quantifying the moisture absorption/desorption at the

***X. Yang** and **S. Vera** are PhD students, **Dr. J. Rao** is a research specialist, and **Dr. P. Fazio** is a professor in the Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Canada. **Dr. H. Ge** is the director of Building Science Center of Excellence, British Columbia Institute of Technology, Burnaby, Canada.*

material surface and the effects of local environments close to the surface.

Moisture Balance

The indoor RH level is governed by the mass balance in the room volume, as shown in Equation 1 and Figure 1 (EI Diasty et al. 1993). The mass balance equation can also be used to estimate the amount of moisture absorbed or released by hygroscopic materials (*dms/dt*), which is, in fact, another method to evaluate the moisture buffering effects in rooms.

$$\frac{dW}{dt} = \frac{1}{\rho_a V}\left[\sum_{i=1}^{ns}\frac{dms_i}{dt} + \sum_{i=1}^{na}\frac{dma_i}{dt} + \sum_{i=1}^{nc}\frac{dmc_i}{dt} + \sum_{i=1}^{ng}\frac{mg_i}{dt}\right] \quad (1)$$

where

W	=	humidity ratio of air (g/kg or grain/lbs)
dW/dt	=	rate of change in air humidity ratio
dms/dt	=	rate of change moisture absorption or desorption by interior materials
dma/dt	=	rate of moisture added or removed due to ventilation and/or air leakage
dmc/dt	=	rate of moisture removed by condensation
dmg/dt	=	rate of moisture generation from indoor sources
ρ_a	=	dry air density in the room volume (kg/m^3 or lbs/ft^3)
V	=	room volume (m^3 or ft^3)

To estimate the amount of moisture absorbed or released by hygroscopic materials (*dms/dt*) in a room, the rest of the terms in Equation 1 must be measured accurately. When condensation on interior surface is not present, the change of moisture in the room air (*dW/dt*) and moisture generation by a humidifier (*dmg/dt*) can be measured by RH probes and load cells, respectively. In contrast, the moisture addition/removal by the ventilation (*dma/dt*) is more difficult to obtain. Direct estimation of this term can be performed by two methods. The first one is the calculation based on the measurements of air flow rate, temperature and RH in the inlet and outlet (RH method). The other method allows measuring the moisture removed within an air handling unit (AHU) system that ventilates the test room (condensed water method). This system requires a special design in the ventilation system and monitoring procedure, which will be presented in the design section.

The objective of this research is to study moisture buffering in a full scale test considering the RH, temperature and air speed distribution across the room, local environments close to the wall surfaces, and moisture content of hygroscopic materials. Additionally, a customized Air Handling Unit (AHU) was designed to evaluate the moisture absorption or desorption of hygroscopic materials, which is used to evaluate the moisture buffering capacity of different finishing materials. This paper briefly describes the experimental set up (Vera et al. 2006), and presents the preliminary results obtained from room 1 at 0.5 air change rate (ACH).

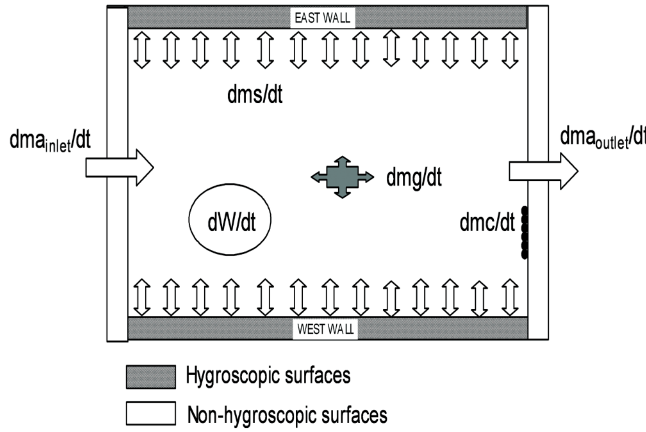

Figure 1 *Representation of moisture balance in a ventilated room with moisture source.*

TEST DESIGN AND SETUP

Configuration

A two-storey test-hut (Figure 2) is built in a large-scale Environmental Chamber, which has dimensions of 10 m (32.80 ft) L × 4 m (13.12 ft) W × 7 m (22.97 ft) H and the capacity to simulate temperature conditions from -40 to 40°C (-40 to104°F) with an accuracy of ±0.1°C (± 1.8 °F), and RH within 1% (Fazio et al 1997). The test-hut construction represents a residential wood-framed construction. Each room is 3.62m long, 2.44 wide, and 2.43 high (11.87ft x 8.00ft x 7.97 ft).

The east and west walls consist of gypsum board as finishing surface material as shown in Figure 2. The rest of the indoor surfaces are covered with aluminum sheets (0.8 mm thickness or 0.03 in.), and the door surfaces are made of PVC. This set up allows only the east and west walls to absorb and release moisture.

Test Conditions

The tests are carried out under typical Montreal's winter condition, -10°C (14°F) and 45% RH. The indoor air supply condition is 17.5 ± 1°C (63.5 ± 1.8°F), 40 ± 3% RH in Room 1 at 0.5 ACH. For each test, the conditions of supply air are maintained constant throughout the experiment and the moisture content is kept at 4.9 g/kg (34.29 grain/lb) for all tested cases. The indoor temperature is maintained between 20.5°C and 21°C (68°F and 69.8°F), while the indoor relative humidity is left floating.

The experiment was designed to study the effect of different variables including four levels of air change rates (0.3, 0.5, 0.75 and 1.0 ACH), three levels of moisture generation rates (between 2 and 8 g/hr·m^3) or (0.87 and 3.49 grain/ft^3.hr), and two types of interior surface materials (gypsum board and wood panel). Tests are carried out in both rooms independently under various conditions. This paper only presents the

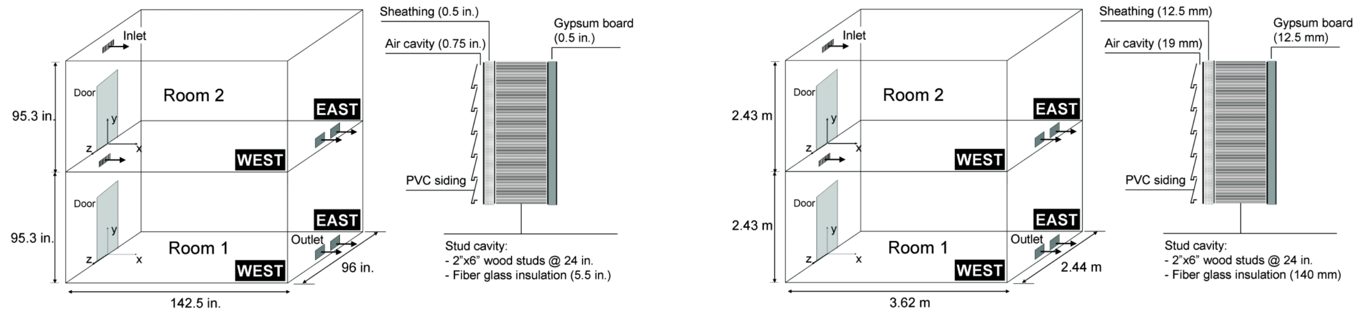

Figure 2 *Configuration of test hut and wall cross section.*

results obtained in Room 1 with gypsum board as interior finishing materials at 0.5 ACH and the moisture generation rate of 4.6 g/hr·m^3 (2.01 grain/ft^3.hr).West and east walls are also covered with polyethylene sheets to represent the case without moisture buffering and the results are used as reference values.

Design of Moisture Generation Equipment

A bedroom situation with a moisture generation profile of 4.6 g/m^{3}hr (2.01grain/ft^3.hr) for ten hours is simulated in this study. The moisture source is located in the center of the rooms at 0.5 m (1.64 ft) above the floor.

The main components of the moisture generation equipment are shown in Figure 3. Water pumped from the water tank drips into the cooking pan on the hotplate, then evaporates immediately and disperses into the indoor air. A load cell beneath the water reservoir is used to monitor the water that is pumped into he hot plate.

Design of AHU System

The ventilation system is a closed system in which air is taken directly from the test room, treated by the AHU, and then sent back to the test room. Each room has an independent ventilation system and AHU. In each room, a heater installed in the bottom part of the door maintains the indoor designed temperature.

The key element of the ventilation system is the AHU shown in Figure 4, which not only provides the supplied air at stable temperature and RH conditions, but also allows collecting water contained in the return air.

In the specially designed dehumidification compartment (lower right in Figure 4), the cold water from a liquid temperature bath is circulated in a water-to-air heat exchanger and cools the air to constant temperature at 3 ^oC (37.4°F). To assure the constant humidity ratio of supply air for different test cases, the fan within the heat exchanger circulates the air through the coil many times inside the dehumidification compartment before the air is pushed further into the upper compartment for heating. This process also permits water vapor in the return air to be fully condensed on the coil surface. The weight of the collected condensation water is monitored

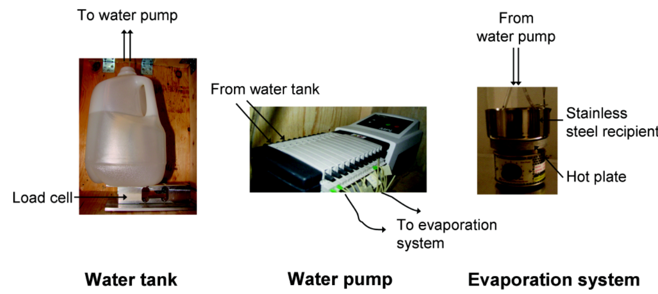

Figure 3 *The picture of moisture generation.*

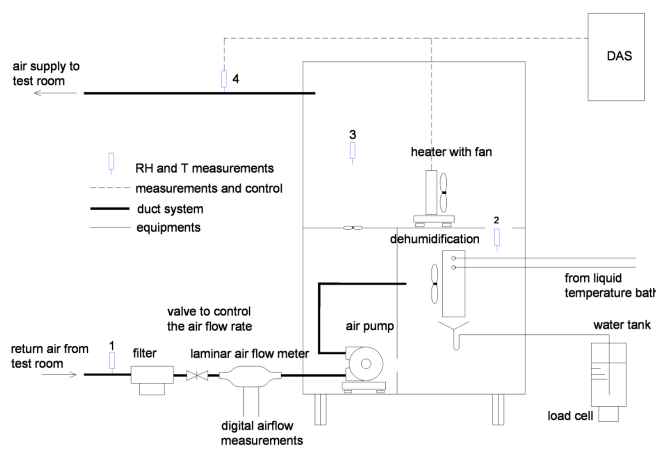

Figure 4 *Components of the air handling unit.*

continuously by a load cell. Given that a thin layer of condensation water film has accumulated during pre-conditioning before each test run, the water flowing down from the coil corresponds to the water actually taken out by the coils. The collected water represents the term *dma/dt* of Equation 1, which is used to estimate the amount of vapor absorbed or released by the gypsum board.

The air pump is installed inside the AHU to assure that any leakage of the pump does not affect the setup. The heater in the upper compartment is used to control the supply air at the designed temperature (0.1°C or 0.18°F accuracy). The small axial fan in the middle divider (between the pump and heater compartments) circulates a small fraction of the cold air into the pump compartment (lower left) to cool down the pump motor. The air flow rate through the entire unit is adjusted manually by a gate valve with precision of 0.02 m^3/hr (0.71 ft^3/hr).

Monitoring Process and Measurements

The parameters monitored include the HAM (Heat, Air and Moisture) response of East and West walls, surface temperature of other walls, ceiling and floor, the indoor environment condition across the room (temperature, RH, and air speed), and the AHU operation (airflow, temperature, RH, and pressure drop).

Temperature and relative humidity are controlled within the environmental chamber to represent exterior winter conditions of Montreal. The HAM response of east and west walls is monitored by temperature, RH and moisture content sensors. Figure 5 shows the location of these sensors in the west wall. In this test a pair of stainless steel screws is used to monitor the moisture content level in the gypsum board. Pretests found that screws provide satisfactory surface contact with the gypsum and give more reliable readings (Figure 6). The screws were inserted into the gypsum by 5-6 mm (0.19-0.23 in.). Delmhorst moisture transmitters (MTC-60) were used to convert resistance to voltage output. To avoid error due to polarization, an alternating voltage was applied to the sensors (Said 2004; Straube et al. 2002).

RH sensors calibrated at 2% accuracy are used to measure RH across the room. In each room, 32 RH sensors were located close to the moisture source and near the surface of East and West walls to measure the moisture distribution across the room. Air speed is measured with 3 and 16 omnidirectional anemometers in Room 1 and Room 2, respectively. More details about these measurements can be found in Vera et al. (2007)

Air Leakage

Although great care was taken to seal the rooms and the box containing the AHU tight, it is impossible to completely eliminate air leakage from the system. Three-stage tests have been carried out to quantify the air leakage rate of the system: firstly, a pressurization test for the AHU box itself; secondly, a pressurization test for the AHU and duct system of the supply air; thirdly, a pressurization test for the whole system including the AHU, duct system and test rooms. In addition, the pressures for the AHU box and room under operating conditions were recorded.

The air leakage rate measured at 50 Pa (0.2 in. water) is 0.26 m^3/hr (9.18 ft^3/hr) for the AHU itself, 0.35 m^3/hr (12.36 ft^3/hr) for the AHU with supply duct system, and 6.57 m^3/hr (232.02 ft^3/hr) for the test rooms. Under operating conditions the recorded pressure is 7.5 Pa (0.03 in. water) for the AHU and -2 Pa (-0.008 in. water) for the test room, therefore, the corresponding air leakage rate is 0.35 m^3/hr (12.36 ft^3/hr) for the AHU and 0.52 m^3/hr (18.36 ft^3/hr) for Room 1. Although the air leakage is low, certain amount of vapor can be transported out of the system, which could affect the amount of condensed water and thus the estimate of *dma/dt*. The moisture carried by the air leakage from the AHU and the test room will be taken into account in the future analysis.

PROCEDURE

The test for each set of parameters lasted 3 days. On the first day the test began with the moisture generation schedule at initial room conditions of approximately 20.5ºC (68.9°F) and 35% RH. It was found that the first cycle is usually disturbed during the first hours due to the setting-up task in the test room. However, the second and subsequent cycles (Figure 7) are identical. Therefore, the data from the second day are used for data analyses.

RESULTS AND ANALYSES

This section presents the preliminary results obtained from room 1 at 0.5 ACH and 4.6g/h m^3 moisture generation rate (2.01grain/ft^3.hr) for the cases of uncoated gypsum board (hygroscopic case) and walls covered with polyethylene sheets (non-hygroscopic case). Firstly, the influence of uncoated gypsum board on the indoor environment is shown.

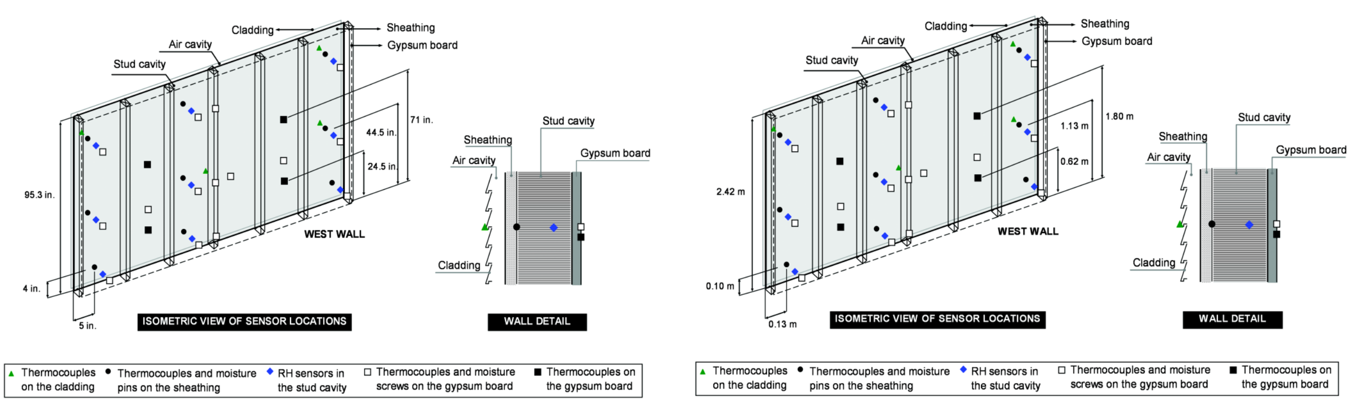

Figure 5 *Typical locations of sensors within the walls.*

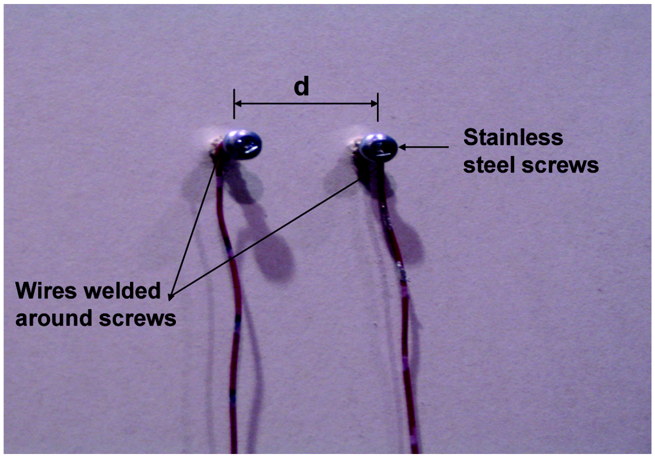

Figure 6 *Stainless steel screws to measure gypsum moisture content (d=2.54 cm or 1 in).*

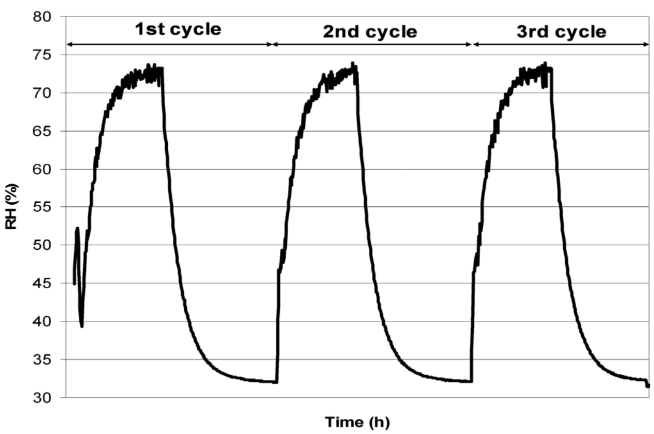

Figure 7 *Identical cycles of RH variation across the room.*

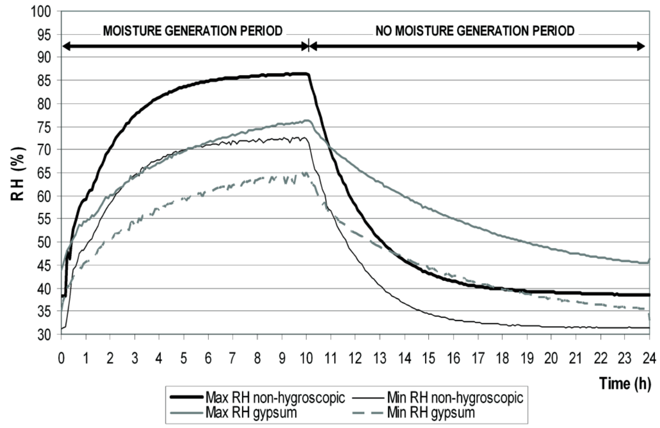

Figure 8 *Maximum and minimum RH across the room.*

Secondly, preliminary calculations of the moisture added/removed by the ventilation system (*dma/dt*) are presented using two methods: the "RH method" and the "condensed water method". Based on these results, the amount of moisture absorbed and released (*dms/dt*) by uncoated gypsum board are presented.

Moisture Buffering Effects on Indoor Environments

Figure 8 and Figure 9 show the maximum and minimum RH and humidity ratio across the room for uncoated gypsum board and non-hygroscopic case. First, it can be seen that the use of hygroscopic finishing materials, such as uncoated gypsum board, can reduce the RH variation from 85 - 32% to 75% - 35%, and humidity ratio variation from 4-11.5 g/kg (27.99-80.49 grain/lb) to 5.5-10.5 g/kg (38.49-73.49 grain/lb). Moreover, in the first 4 hours of moisture generation, the increment in RH and humidity ratio is much smaller with uncoated gypsum board than with polyethylene sheets. These results show that uncoated gypsum board is absorbing moisture from the environment, thus reducing the RH and humidity ratio inside of the room. A similar situation occurs after the moisture generation stops, the decay of RH is much slower with uncoated gypsum because this material is releasing the moisture absorbed in the previous period.

The readings from screws on the gypsum board are shown in Figure 10, which is expected to represent the maximum moisture content along 6 mm (0.24 in.) depth of gypsum board. Gypsum board is extremely dry at the beginning (0.2% moisture content), but when moisture generation starts it begins to absorb moisture immediately, reaching 0.9 to 1% moisture content. The moisture content of gypsum board decreases when there is no moisture generation until it reaches its initial moisture content. It should be noted, that measuring moisture content of gypsum board under 1% is very difficult, but the setup implemented follows quite well the expected absorption/desorption behavior of uncoated gypsum boards.

Preliminary Estimation of *dma/dt* and *dms/dt*

Two methods are used to find *dma/dt*, which is an essential value required to calculate *dms/dt* using the moisture balance equation. The "RH method", consists calculating *dma/dt* based on the airflow rate (measured by a laminar flow element with an accuracy of 1%), and RH sensors (with an accuracy of 1% RH and ±0.1°C or 0.18 °F) placed in the inlet and outlet (see Equation 1). The "condensed water method" collects the water that condensed in the AHU, which corresponds to the moisture taken from the exhaust air. Figure 11 shows *dma/dt* for both methods for the case with uncoated gypsum board. At the end of the cycle, the condensed water method yields 86.8 g (1339 grain) of water more than the RH method. This difference can be carried out by the calculation errors of the RH method due mainly to the accuracy of the RH sensor. Further analyses are being carried out to determine the origin of this difference.

Based on the calculation of *dma* using the condensed water method, the amount of water vapor absorbed/released by the gypsum board during the test was calculated. In Figure

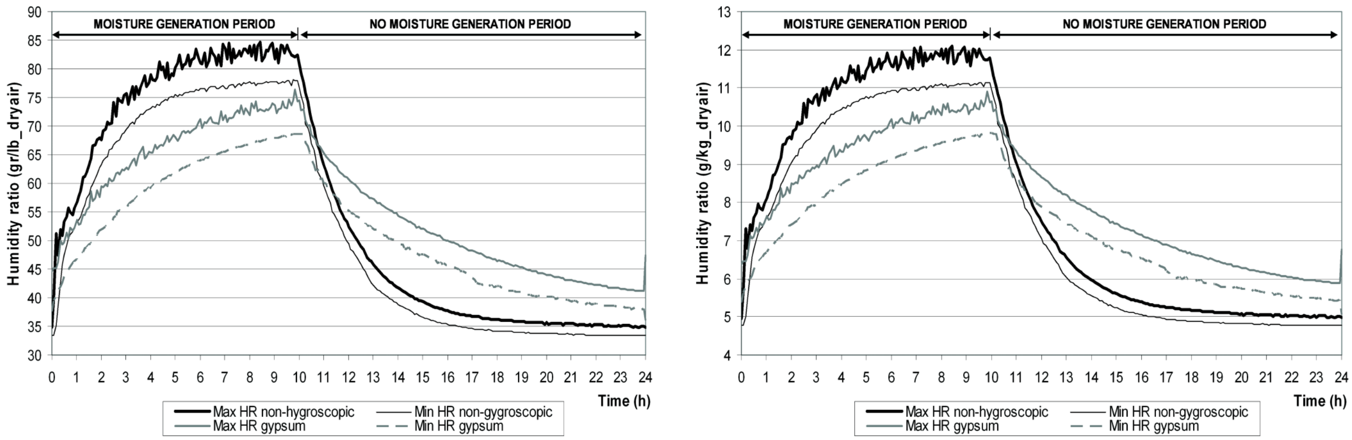

Figure 9 *Maximum and minimum humidity ratio across the room.*

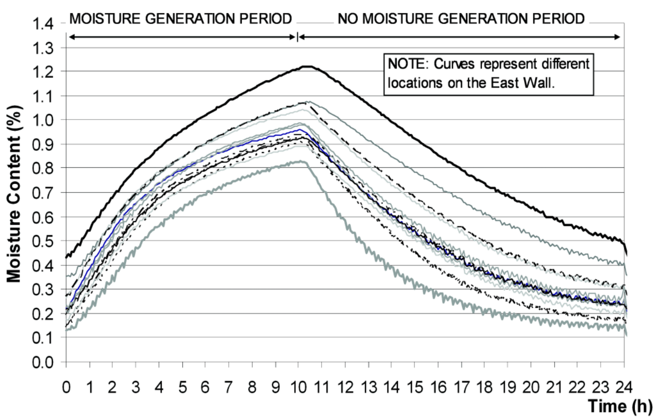

Figure 10 *Measurements of moisture content of gypsum board by means of stainless steel screws for all sensors on East wall.*

12, it can be seen that 175 g (0.39lbs) of moisture was absorbed by the uncoated gypsum board, which corresponds to 9.9 g/m^2 (14.19 grain/ft^2). However, this value should be corrected according the air leakage rate to give the accurate amount of the moisture buffering capacity of uncoated gypsum board.

CONCLUSIONS

An experiment on a large-scale test-hut has been set up to study the influence of different ventilation rates, moisture generation rates, and different indoor finishing materials on the moisture buffering and moisture distribution inside two test rooms. The traditional approach evaluating moisture buffering capacity of hygroscopic materials is mainly focused on its effect on moderating the indoor environment. A new approach, which is to evaluate the amount of moisture absorbed/released by the hygroscopic materials, is employed in this research. The amount of moisture absorbed by the uncoated gypsum board was calculated based on the moisture collected from the return air by a specially designed AHU.

Preliminary results obtained at 0.5 ACH and 4.6 g/h m^3 (2.01 grain/ft^3.hr) moisture generation rate show that the indoor RH and humidity ratio was reduced up to by 10% and 1g/kg (6.99 grain/lbs) respectively when uncoated gypsum board is used. The RH difference across the room is highly spreading up to around 15% at high indoor RH level. It means that local microclimates vary, which could influence the moisture buffering capacity, and increase the risk of surface condensation and mold growth. Further analyses are being carried out to study this with other parameters, such us surface temperature, air speed close to walls, etc.

Finally, the "condensed water method" and "RH method" to calculate *dma* were compared, and the amount of moisture absorbed by gypsum (*dms*) was calculated. At the peak, the uncoated gypsum could absorb as much as 175 g (0.39lb) or 9.9 g/m^2(14.19 grain/ft^2).

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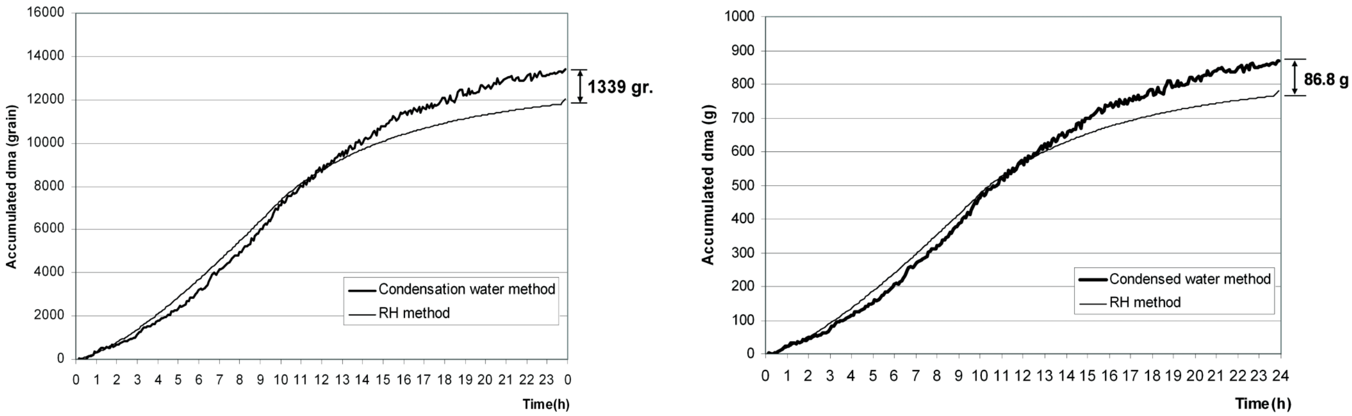

Figure 11 *Comparison of dma based on condensed water and RH methods.*

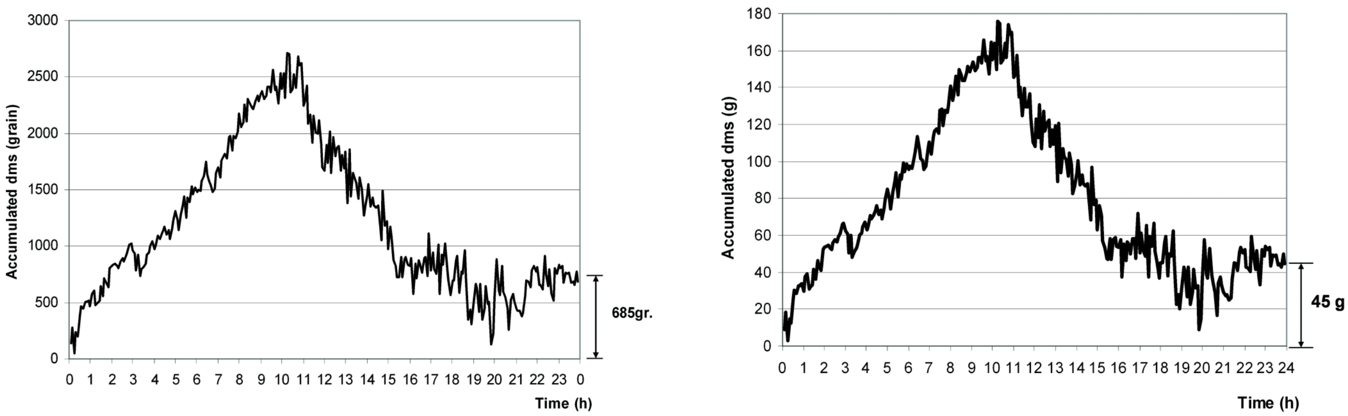

Figure 12 *Moisture absorbed/released (dms) by uncoated gypsum.*

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