MOISTURE BUFFERING AND VENTILATION STRATEGIES TO CONTROL INDOOR HUMIDITY IN A MARINE ENVIRONMENT: A FIELD EXPERIMENTAL STUDY

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ABSTRACT

Control of the indoor humidity in a marine climate is a challenge, especially under operating conditions where high indoor humidity is a norm. Outdated mechanical equipment, inefficient ventilation design, and occupants' life styles are some of the contributing factors to high indoor humidity.

In this field experimental study, the moisture buffering potential of unfinished drywall in reducing daily indoor humidity peaks, coupled with various ventilation strategies are investigated. Two identical test buildings exposed to real climatic conditions in Burnaby, BC are monitored under varying ventilation rates and schemes.

The interior of the test building is clad with unfinished drywall, while the control building is covered with polyethylene, which has negligible moisture buffering. In this way, the moisture buffering potential of drywall under four test cases is isolated. Under the test cases, the indoor air quality in terms of CO2 concentration, and ventilation heat loss of the two buildings are also evaluated.

The results show that the moisture buffering potential of drywall effectively regulates indoor humidity peaks, and maintains relative humidity levels within acceptable thresholds, when coupled with adequate ventilation as recommended by ASHRAE. When coupled with time-controlled and demand-controlled ventilation schemes, the moisture buffering effect of drywall shows competing benefits when it comes to managing indoor humidity, indoor air quality, and minimizing ventilation heat loss.

INTRODUCTION

In the Lower Mainland of BC, many buildings have undergone rehabilitation to prevent water ingress and deterioration following widespread poorly constructed leaky condos from the 1980s and 1990s. To prevent future rainwater penetration from the exterior, the building enclosures are designed for better water shedding and watertightness. Rehabilitation of the building enclosure for preventing water ingress also presents opportunities to improve the airtightness. Building retrofits such as those extensively done in the Lower Mainland of British Columbia for water ingress prevention or elimination have resulted in significantly more airtight buildings. However, in many instances, the enclosures were made more airtight without consideration for the need to increase ventilation (Roppel et al., 2007). Adequate ventilation is crucial especially when moisture production of occupants may exceed design moisture loading. Without adequate ventilation, tighter

building enclosures will generally result in elevated humidity levels and higher humidity peaks, and increase the risk of condensation in the building enclosure and on cold surfaces such as window glazing.

Staying within this range is challenging for buildings located in marine climates such as the Pacific Northwest of the United States, and southern West Coast of British Columbia. In these climates, the outdoor air temperature is mild and the air is humid. Therefore, ventilation alone may not suffice in managing indoor moisture, especially if moisture generation of occupants exceeds the design moisture generation rate. In these climates, further passive measures such as the aid of moisture buffering materials, or active measures such as dehumidification may be required to manage indoor moisture. Condensation can adversely affect the durability of a building. Chronic condensation and moisture accumulation leads to deterioration of the building enclosure and structural materials, such as softening of gypsum drywall, wood decay, corrosion of steel, peeling of paint finishes, damage to moisture sensitive insulation, and growth of mould, mildew, and fungi which can be detrimental to health (HPO, 2006). With rehabilitation resulting in tighter building enclosures, sufficient ventilation measures are required to avoid building durability issues. Sufficient ventilation can be achieved by means of retrofitting mechanical systems such as installing exhaust fans where there are none existing, upgrading existing exhaust fans to a higher flow rate model, implementing make-up air supply systems or heat recovery ventilators. Physical constraints of the building or cost limitations may render mechanical ventilation retrofits infeasible, in which case opening windows or running exhaust fans more frequently or continuously are required to reduce indoor humidity. Opening windows and running ventilation fans more frequently may address condensation and durability issues, but since more heating energy is required for additional outdoor air intake, they are also measures that compromise energy efficiency.

The intent of ventilation is to promote good indoor air quality by diluting or displacing indoor air ridden with pollutants and odours and allowing outdoor air to replace displaced air. In cold climates, it also allows indoor moisture-laden air to be exhausted to the exterior and be replaced with dryer outdoor air. Ventilation of indoor air also allows for removal of excess indoor moisture and management of indoor humidity.

The upper and lower relative humidity threshold of indoor spaces is debated. In general, consensus is that interior relative humidity should not exceed 60% (70% at a building surface) to avoid mould growth and germination. The lower threshold is less concrete, however ASHRAE recommends that indoor relative humidity stay above 25% to avoid irritation of the respiratory mucus membrane and the eyes (Lstiburek, 2002).

The motivation for this research comes from a low-income housing reference building in Vancouver, BC with high indoor humidity and building durability issues brought on by air-tightening the building enclosure following rehabilitation. Implementation of new ventilation exhaust fans and operating schemes were not sufficient in addressing the building humidity and durability issues. Field experiments were designed to mimic the scenario of a suite in the low-income housing reference building and used to develop solutions to address the high indoor humidity problem, while also considering heat loss through ventilation and indoor air quality. The effect of moisture buffering of interior gypsum board as a passive means to reduce indoor humidity was investigated.

METHODOLOGY

Two test building facilities with identical roof and floor assemblies, dimensions, orientation, and location were monitored to compare the effects of moisture buffering properties of gypsum wallboard and varying ventilation schemes on indoor humidity and air quality conditions (Figure 1). The buildings are located in Burnaby, British Columbia, an area characterized by mild climate, warm summers and cool rainy winters. All exterior boundary conditions during the monitoring period were recorded by a weather station on site. Tariku, et al. (2013) outline the design, construction, systems, and equipment of the buildings in more detail.

Figure 1: Two test building facilities used for the experimental study

A field experiment is designed to simulate the conditions of a residential suite and measure the response in indoor conditions under varying outdoor conditions, and ventilation strategies in the presence of moisture buffering and no moisture buffering. Daily indoor moisture and CO2 generation profiles are determined based on analysis of real occupants in a 'Reference Building' described later in this paper. Indoor moisture and CO2 is released in the field experiments based on the predetermined daily profiles using programmable occupant simulator units. The ventilation system operates as per pre-defined ventilation schemes for four different test cases. For each test case, the performances of hygroscopic versus non-hygroscopic interior finished buildings are directly compared for the same outdoor conditions. Performance of the buildings across test cases is also compared.

EXPERIMENTAL SETUP

Table 1 lists the parameters and variables for each of the buildings for test cases defined. Each test case is run for approximately one week. One or more days are dedicated to conditioning the materials for each test case, in order to reach quasi-equilibrium. With these field experiment test cases, it will be possible to assess the effects of the variable test parameters: the effect of ventilation strategy, and moisture buffering of gypsum wallboard on indoor relative humidity, indoor air quality, and ventilation heat loss.

Table 1: Test cases and respective parameters and variables in each test and control buildings

Test Period			Control Building (North Building)	Test Building (South Building)
Test #1	Apr. 2-4/14	**Finish Material**	Polyethylene	Unpainted gypsum board
		Ventilation Rate	15 CFM	15 CFM
		Ventilation Scheme	Constant	Constant
Test #2	Apr. 12-14/14	**Finish Material**	Polyethylene	Unpainted gypsum board
		Ventilation Rate	30 CFM at 8am - 12pm and 7pm - 11pm, 7.5 CFM all other times	30 CFM at 8am - 12pm and 7pm - 11pm, 7.5 CFM all other times
		Ventilation Scheme	Time-controlled	Time-controlled
Test #3	Jun. 22-24/14	**Finish Material**	Polyethylene	Unpainted gypsum board
		Ventilation Rate	7.5 CFM at 50% RH or less, 30 CFM at 60% RH or more, between 50-60% RH linearly increasing CFM between 7.5 and 30 CFM	7.5 CFM at 50% RH or less, 30 CFM at 60% RH or more, between 50-60% RH linearly increasing CFM between 7.5 and 30 CFM
		Ventilation Scheme	RH-controlled	RH-controlled
Test #4	Jul.5-7/14	**Finish Material**	Polyethylene	Unpainted gypsum board
		Ventilation Rate	7.5 CFM at 800ppm or less, 30 CFM at 1000ppm or more, between 800-1000ppm linearly increasing CFM between 7.5 and 30 CFM	7.5 CFM at 800ppm or less, 30 CFM at 1000ppm or more, between 800-1000ppm linearly increasing CFM between 7.5 and 30 CFM
		Ventilation Scheme	CO_2-controlled	CO_2-controlled

One building is clad with unpainted gypsum board on the interior of the building enclosure, which has hygroscopic properties and is designated as the test building (South Building). The non-hygroscopic building is covered with 6 mil polyethylene vapour retarder on all interior surfaces and is the designated control building (North Building). Both the test and control building are exposed to the same variables for a given test case, however, the test building has moisture buffering potential, while the control building has the moisture buffering effect eliminated. Other than vertical wall surfaces, all surfaces of the interior of the buildings exposed to test conditions were isolated during testing; the concrete floor, footings, and ceiling were sealed with 6 mil polyethylene vapour retarder to prevent possible interactions between those materials and moisture inside the test space (Figure 1).

Indoor Moisture and CO_2 Load

Moisture generation is simulated by releasing moisture and CO_2 hourly based on occupants' behaviour in the real occupied 'Reference Building,' using the automated occupant simulator units. To isolate the moisture production of occupants and their activities, indoor conditions of a two-bedroom apartment suite in a 'Reference Building' were analyzed. The suite is occupied by a family of four, two adults and two children and covers 643 ft^2 (59.7m^2) of area, and with a clear height of 8 ft encompasses 5144 ft^3 (149 m^3) of volume. The north-facing wall is the only exterior wall of the suite. This wall has one window in each bedroom, and a balcony adjacent to the living room. All other walls are adjacent to other suites or the building corridor. The kitchen is enclosed by interior walls on three sides and open to the living room on one side. The bathroom is located near the entrance door of the suite. The suite has a bathroom exhaust fan, which is intermittently on at 7-11 am and 6-10 pm. The kitchen is equipped with a range hood fan that is turned on manually. Fresh air is supplied to the suite through open windows, the balcony door, and the entrance door undercut.

Figure 2 show daily relative humidity profiles of the interior of the suite for 90 days of monitoring completed

between December 1st, 2010 and February 28th, 2011. Ventilation periods are highlighted with blue shading. A typical daily moisture generation profile was determined from this data using statistical analysis, which is further outlined in Pedram & Tariku, (2015). Typical moisture loading identified by Kunzel, et al. (2004) in studies of German homes is about 48g/m^3 per day. This corresponds to 1.9 kg of moisture per day for a building with a volume of 40.5m^3, the size of the ones at the test building facilities used. The total moisture production per day of the typical moisture generation profile obtained based on the monitoring data from the 'Reference Building' scaled down to the size of the test building facilities equates to 1.9 kg/day, which is in line with the findings from this study.

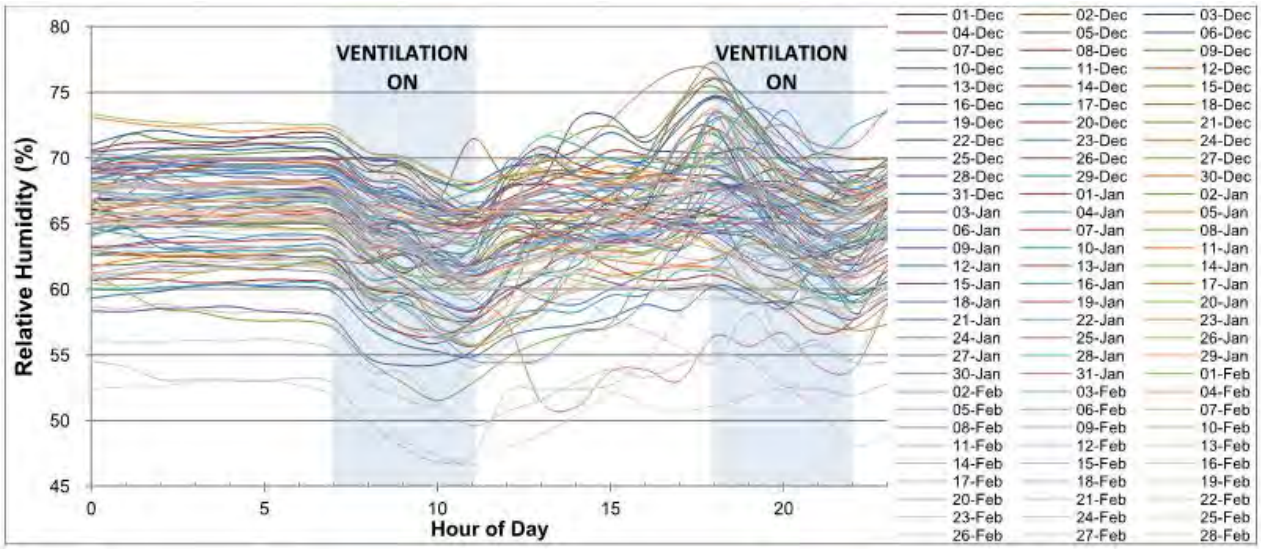

Figure 2: Daily relative humidity profiles of suite in the 'Reference Building' for 90 days of monitoring.

An image of the occupant simulators' moisture dispensing unit is shown in Figure 3, which was used to release predetermined rates of moisture throughout the day in the field experiment, based on the typical daily moisture generation profile obtained from the 'Reference Building' data.

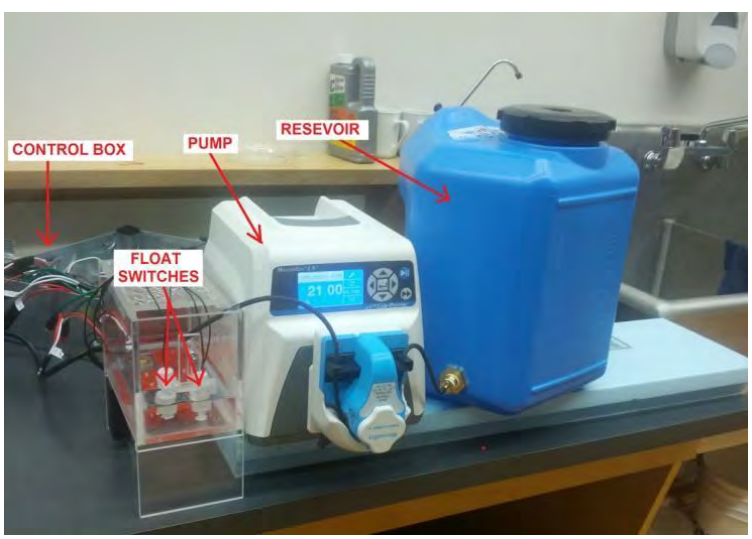

Figure 3: Occupant simulator equipped with control box, humidifiers, water reservoirs, pumps, CO2 release valve (not shown), and heat generating bulb (not shown)

Because it is difficult to measure odour intensity in a space, CO2 concentration is typically used as a surrogate

indicator to evaluate the indoor air quality and ventilation adequacy of a space. CO2 concentration in a building is dictated by the occupants, as well as the CO2 levels in the ambient outdoor air. CO2 production rate depends on the occupants' level of activity and diet. CO2 generation per person can be estimated using the oxygen consumption rate, from Equation 1 given in ASTM Standard D6245 (2012).

Equation 1: Oxygen Consumption of Occupants (ASTM D6245, 2012)

$$V_{O_2} = \frac{0.00276\ A_D\ M}{0.23\ RQ + 0.77}$$

V_{O_2} = Oxygen consumption rate [L/s]
A_D = DuBois body surface area [m^2]
M = Metabolic rate per unit of surface area [1 met = 58.2 W/m^2]
RQ = Respiratory quotient, volumetric ratio of CO_2 produced to oxygen consumed [unitless]

To determine the rate of CO2 emission of the occupant simulators for the testing, the level of occupants' activity was assumed for a typical day based on results of a questionnaire outlining their presence and typical activities in the suite. Figure 4 shows the assumed level of activity for the family of four throughout the day, assuming there are two adults, one who works from home with two children. The metabolic activity rates were estimated from each occupant's level of activity as outlined in Figure 4, from Equation 1, and corresponding CO2 generation rates were determined based on oxygen consumption rate and RQ. Body surface area was assumed to be 1.8 and 1.0 m2 for adults and children respectively. RQ was assumed to be 0.83. When scaled down by the volumetric ratio of the 'Reference Building' to the test buildings, the occupants' normal and peak activity CO2 generation rates are 0.20 and 0.33 L/min respectively.

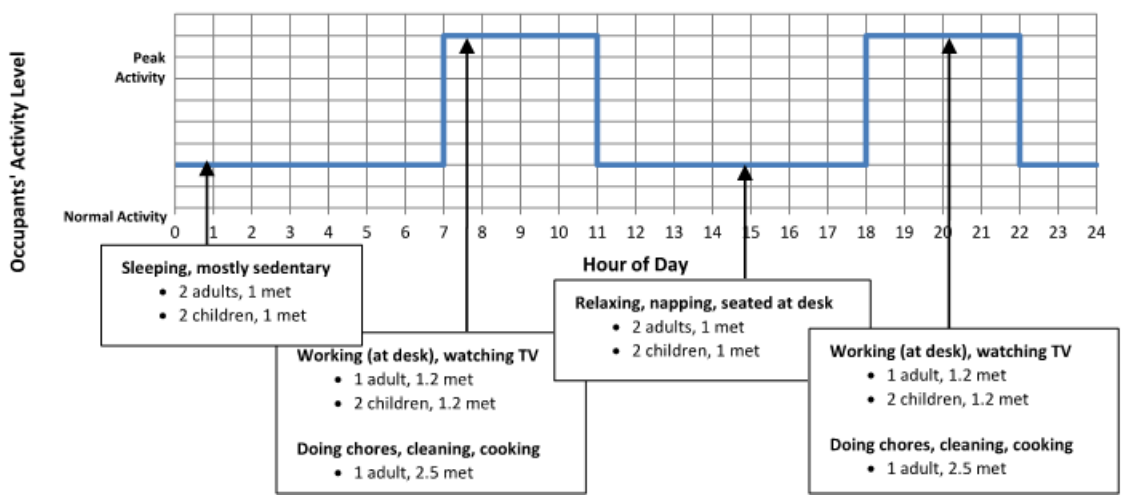

Figure 4: Typical activities of a family of four throughout the day and their corresponding metabolic activity

A solenoid valve on the occupant simulator units' CO2 dispensing system requires voltage input for release of predetermined rate of CO2 into the room. The rate of CO2 release varies linearly with the voltage. CO2 generation profile from Figure 4 was achieved in this way, by providing the resulting voltage for each hour of the day in occupant simulator control system program.

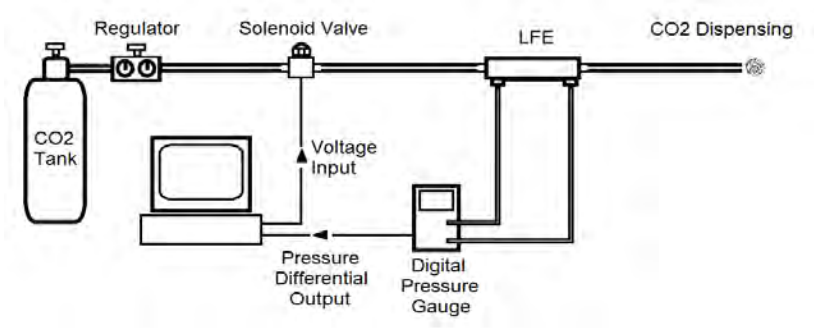

Figure 5: Schematic of carbon dioxide dispersion system

Ventilation Strategies

Both the test and control buildings are equipped with a supply ventilation system to provide outdoor air under continuous, time-controlled, relative humidity-controlled (RH-controlled), and CO_2-controlled ventilation schemes. For the purposes of the field experiments, 100% non-conditioned fresh air is supplied to the test space. This is so that the typically wet and moist marine climate air of coastal British Columbia is used to ventilate the building, as is typical of residential housing in the region. The four different ventilation schemes are tested as follows:

1) **Constant:** The supply ventilation system is run continuously at a constant rate of 15 ft^3/min. (CFM). The ventilation rate is determined based on ASHRAE recommended rates according to Standard 62.1, and scaled down for to the size of the test building facilities

2) **Time-controlled:** The ventilation system supplies fresh air at a ventilation rate of 30 CFM during predetermined on-times for 4 hour durations twice per day at 8am-12pm and 7pm-11pm, which correspond with periods of high moisture generation (typically showering in the morning time, and cooking in the evening). The maximum ventilation rate times are offset from the moisture peak times by one hour due to the gradual rise in humidity levels within the first hour of peak moisture loading. At all other times, ventilation rate is run continuously at 7.5 CFM.

3) **RH-controlled**: The ventilation system supplies fresh air at 7.5 CFM at relative humidity levels of 50% or less, and at 30 CFM at relative humidity levels of 60% or more. Between 50 to 60% relative humidity, the rate increases linearly between 7.5 and 30 CFM.

4) **CO_2-controlled**: The ventilation system supplies fresh air at 7.5 CFM at CO_2 levels of 800ppm or less, and at 30 CFM at CO_2 levels of 1000ppm or more. Between 800 to 1000 ppm, the rate increases linearly between 7.5 and 30 CFM.

The ventilation schemes are summarized graphically in Figure 6.

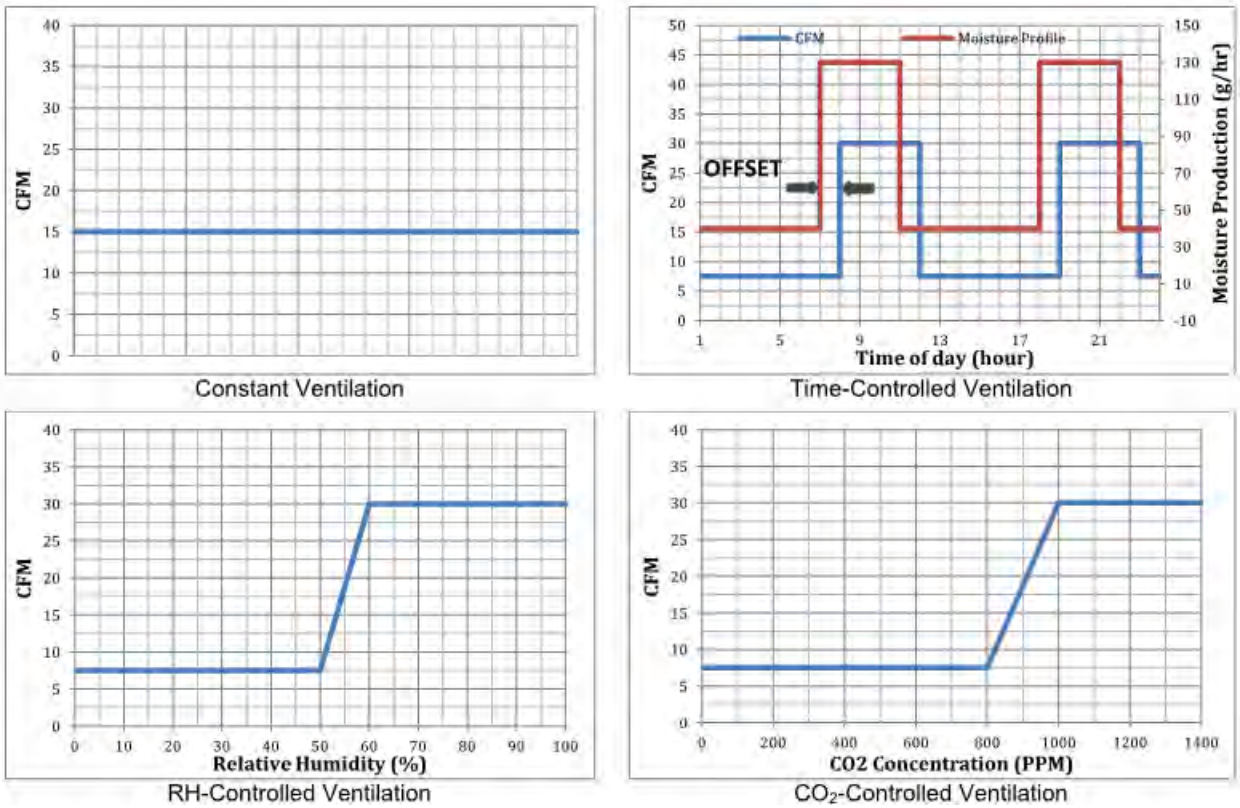

Figure 6: Ventilation rates (in ft^3/min.) and schemes for constant, time-controlled, RH-controlled, and CO_2-controlled ventilation

RESULTS

Previous field testing (Pedram & Tariku, 2014) reveals that moisture buffering properties of gypsum wallboard in the test building is generally effective in regulating the interior relative humidity levels, especially RH peaks, to varying degrees depending on ventilation rate and moisture loading.

The test cases presented here seek to couple the benefits of passive moisture management from moisture buffering, with active moisture management of various ventilation schemes. The effect of constant, time-controlled, RH-controlled, and CO_2-controlled ventilation on indoor humidity, indoor air quality, and ventilation heat loss are further analysed.

Indoor Humidity

Figure 7 shows the relative humidity levels for the test and control buildings, and their respective ventilation flow rates over time for each of the test cases. The effect of the moisture buffering of gypsum board in regulating relative humidity amplitudes is apparent between the test building and the control building, as demonstrated in Figure 7 for constant ventilation; the relative humidity peaks and lows are dampened. A similar effect is seen under the time-controlled ventilation scheme. However, the effect of moisture buffering under the demand-controlled ventilation schemes (RH- and CO_2-controlled) is not as pronounced.

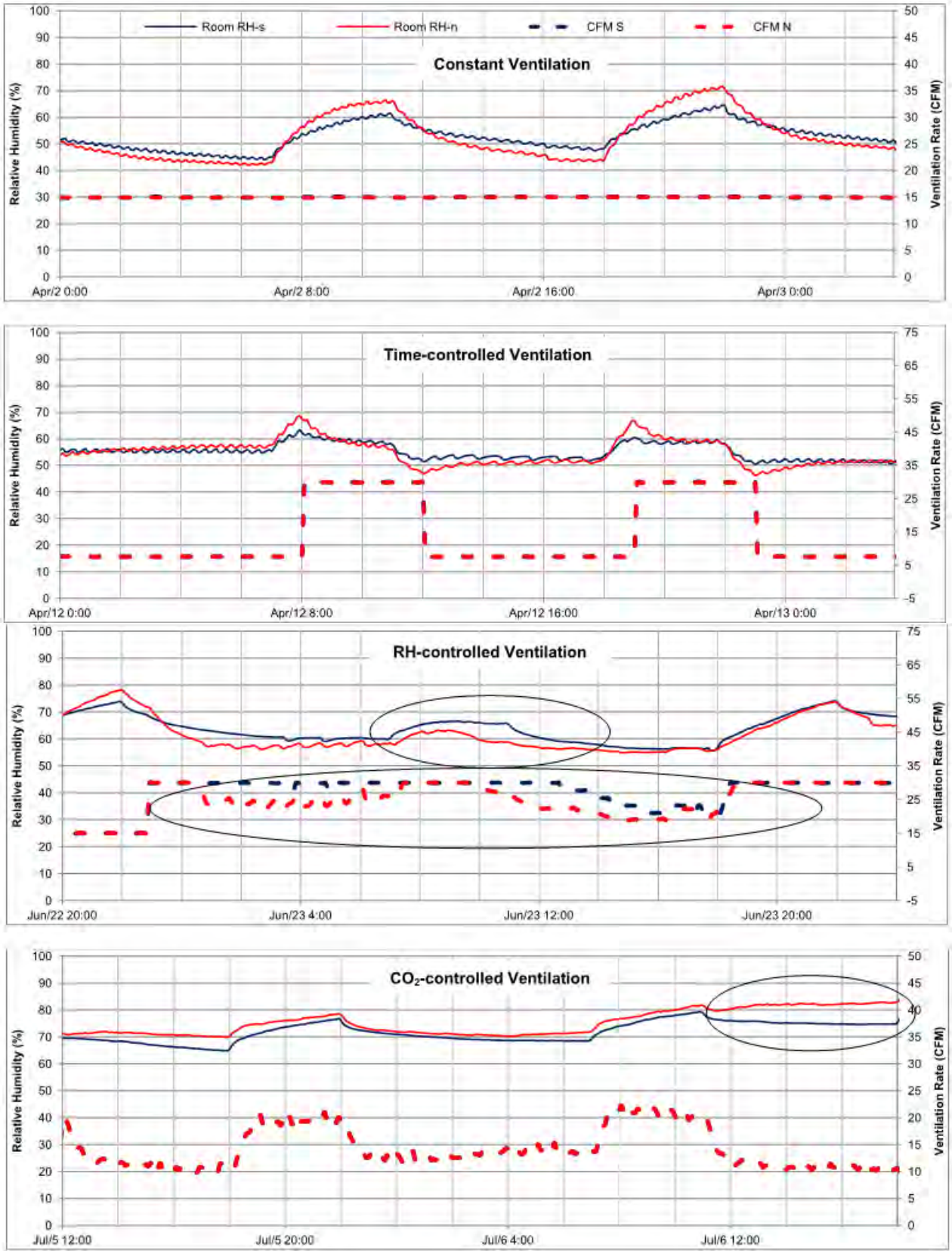

Figure 7: The indoor relative humidity and ventilation rate of the control building (red) and test building (blue) under constant, time-controlled, RH-controlled, and CO_2-controlled ventilation

Upon a closer look at the results, it appears that moisture buffering results in elevated relative humidity levels in comparison to the control building under RH-controlled ventilation. When the relative humidity threshold is exceeded, maximum ventilation rate causes relative humidity levels to drop more quickly in the control building while the test building responds to changes in ventilation rate slowly due to the effect of moisture buffering. This phenomenon can also be seen in other test cases during decreasing relative humidity in the variation cycles. This is due to residual moisture in unfinished gypsum board gradually undergoing desorption back into the air as the relative humidity levels in the test space decrease.

In general, the moisture levels in the test building are not synergistic with RH-controlled ventilation due to slow change in relative humidity response to changing ventilation rates. Maximum ventilation rate is run for a longer duration in the test building, which can in fact increase ventilation heat loss, and have negative impacts on the building energy demand. In the case of continuous, time-controlled, and CO_2-controlled ventilation, moisture buffering effectively reduces humidity peaks and dampens the moisture level fluctuation cycles.

The best way to quantify the effectiveness of moisture buffering, is to look at the difference in amplitude of the relative humidity levels for each moisture loading cycle. Amplitude can be determined from the difference between the maximum relative humidity and minimum relative humidity for each cycle. Figure 8 demonstrates how to determine relative humidity amplitude. While moisture buffering reduces amplitude, it does not reduce the effective mean relative humidity. However, increase in ventilation will reduce mean relative humidity levels.

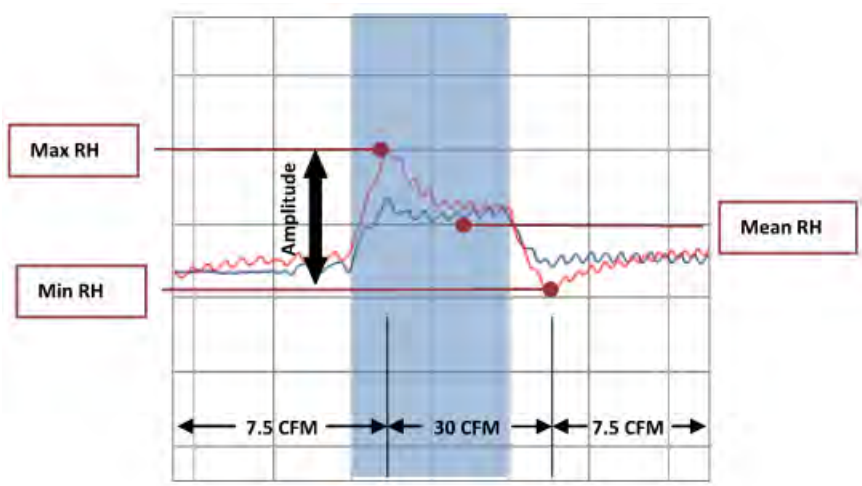

Figure 8: Maximum RH, minimum RH, RH amplitude and mean RH levels in one moisture loading cycle as shown for the control building in red

Figure 9 shows the relative humidity amplitude of Cycles 1 and 2 for each test case. Under time-controlled ventilation, the percent difference in relative humidity amplitudes between the control and test building are more than double, 157% and 111% for Cycles 1 and 2 respectively (Figure 10). This indicates that time-controlled ventilation is the ventilation scheme that successfully works best with the relative humidity regulating benefit of moisture buffering. Under RH-controlled and CO_2-controlled ventilation, the percent difference in relative humidity amplitude is much lower between the two buildings, equal to or less than 20%. This indicates that the regulating effect of moisture buffering is not effective under these ventilation schemes. Under the constant ventilation scheme, the percent difference in relative humidity amplitude between the two buildings is greater than 50% for each cycle. Thus, relative humidity is regulated under this scheme, but

comparatively to a lesser degree than under time-controlled ventilation.

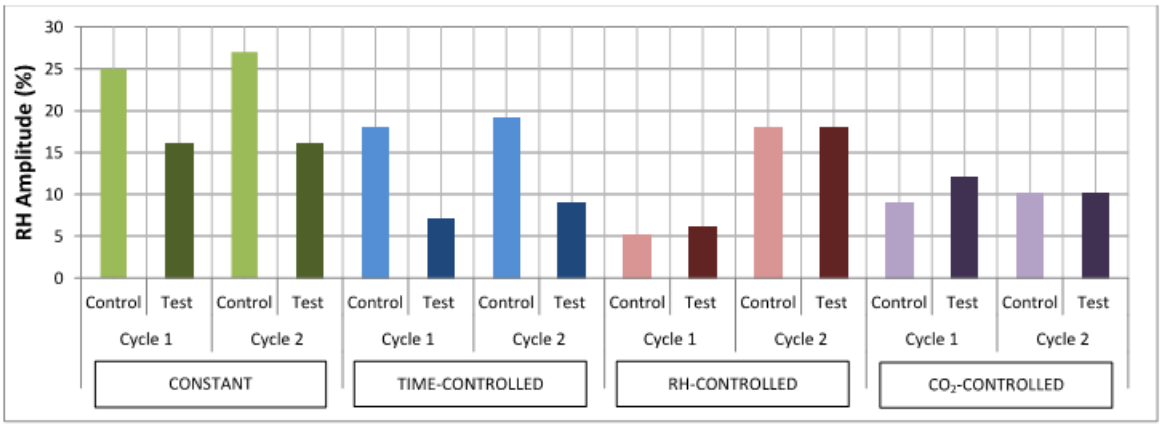

Figure 9: RH amplitude (Max RH – Min RH) for Cycle 1 & 2 from test cases constant, time-controlled, RH-controlled, and CO_2-controlled ventilation schemes.

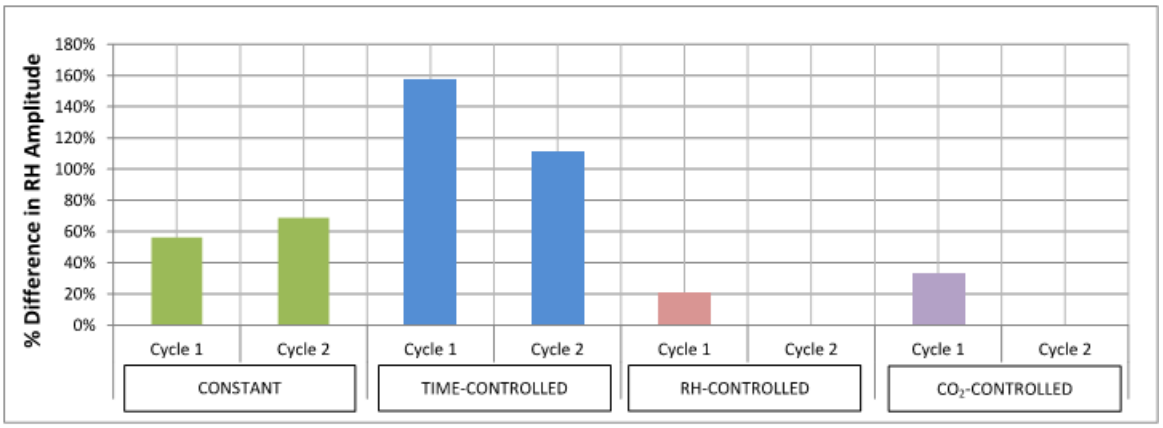

Figure 10: Percent difference in RH amplitudes between the control and test building from the test cases

Based on these results, if RH-controlled ventilation is implemented as a means of controlling indoor humidity, the implementation of moisture buffering materials as means to control humidity peaks in tandem is not recommended. More exploratory investigations are required in this regards, such as modeling, sensitivity analysis, and further field testing.

Indoor Air Quality: CO_2 levels

In part, CO_2 levels are dependent on outdoor CO_2 levels which generally range between 350 to 450 PPM (Dlugokencky & Pieter, 2016). Locally, the outdoor CO_2 levels at the test facilities were measured to be within this range during testing.

Figure 11 shows the maximum, minimum and mean CO_2 levels for each cycle in all test cases. Under constant and time-controlled ventilation, the mean CO_2 levels are above or within 1000 PPM – ASHRAE recommended levels for good indoor air quality – and maximum CO_2 levels consistently exceed this level. Under RH-controlled and CO_2-controlled ventilation, the CO_2 levels are consistently below 1000 PPM.

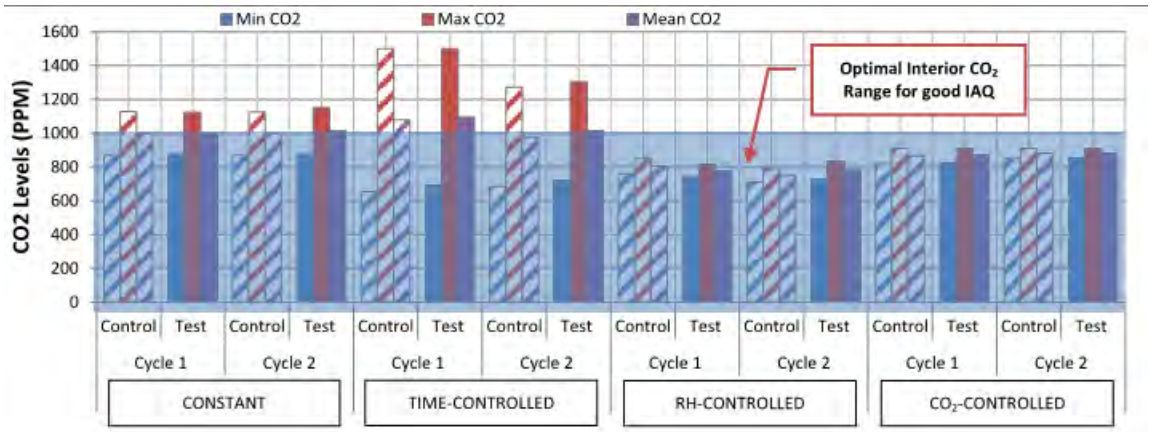

Figure 11: Minimum, maximum, and mean CO_2 for Cycle 1 & 2 for all test cases. The test building is shown in solid and the control building is shown in hatched. Optimal interior RH range is highlighted in blue.

Table 2 shows the total percentage of time CO_2 levels exceed 1000 PPM in each building for the total duration of the data presented for each test case. According to analysis of CO_2 levels, indoor air quality exceeds acceptable levels under constant and time-controlled ventilation for nearly half of the testing period.

Table 2: Percent of time CO_2 levels exceed 1000 PPM threshold

Ventilation Scheme	Control Building	Test Building
Constant	40%	48%
Time-controlled	51%	55%
RH-controlled	0%	0%
CO_2-controlled	0%	0%

While RH-controlled and CO_2-controlled ventilation result in CO_2 levels being maintained at desirable levels, there are implications for heating energy of the buildings. When the space is over-ventilated, good indoor air quality is maintained, but energy consumption may be compromised. Therefore, there may be a tolerance for CO_2 levels exceeding the threshold for a short period of time, if RH levels and heating energy is optimized.

Energy: Ventilation Heat Loss

Heat loss of the buildings can occur through three ways: transmission losses to the exterior through the building envelope, radiation heat losses, and ventilation heat losses. Given that the building enclosure characteristics, indoor, and outdoor temperatures are similar for each building during each test case, the radiation and transmission heat losses can be considered equal. For a given ventilation scheme, if the ventilation rates are the same in both buildings, the ventilation heat losses are also considered equal.

However, ventilation heat loss varies between the buildings where demand-controlled ventilation results in different ventilation rates over time. The ventilation heat loss for the test cases is calculated per Equation 2:

Equation 2: Ventilation heat loss (J/s)

$$Q = \dot{m} \cdot c_p \cdot \Delta T$$

Q = ventilation heat loss [J/s]
$\dot{m}$ = airflow (ventilation) rate [m^3/s]
c_p = specific heat of dry air [1007 J/kg.°C]
ΔT = indoor-outdoor temperature differential [°C]

In order to compare the ventilation heat loss as a result of each ventilation scheme directly, the energy required to maintain the interior temperature set points at around 20°C is obtained. The total ventilation heat loss energy is determined by calculating the estimated area under each Q curve.

For consistency, the ventilation heat loss energy for each building is calculated over a 28 hour period as shown in Figure 12. Note that cooling energy (area between negative Q values and 0 J/s) was included as an absolute value in the summation to include both heating and cooling energy.

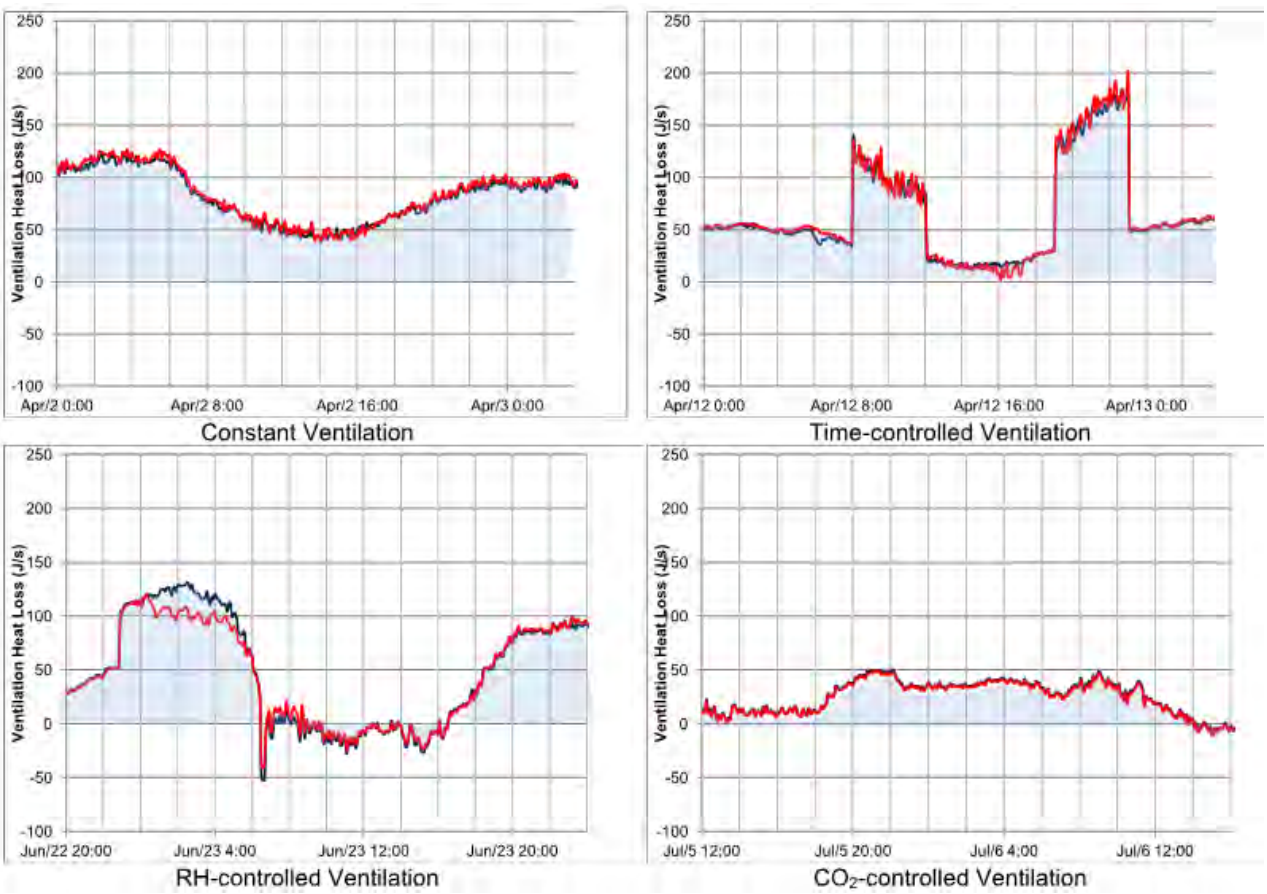

Figure 12: Area under each ventilation heat loss (Q) curve used for calculation of heat loss energy each test case constant, time-controlled, RH-controlled, and CO_2-controlled ventilation scheme.

Figure 13 shows a summary of the total energy due to ventilation heat loss for each building under each test case. Energy is calculated in kilojoules, however, values are also converted to and indicated in kilowatt-hours above each bar for easy comparison. RH- and CO_2-controlled ventilation show improved ventilation energy savings in comparison to the latter two test cases. However, since these test cases took place in the months of June and July respectively, their comparison to constant and time-controlled ventilation can be misleading, given the outdoor temperature dependence of ventilation heat loss.

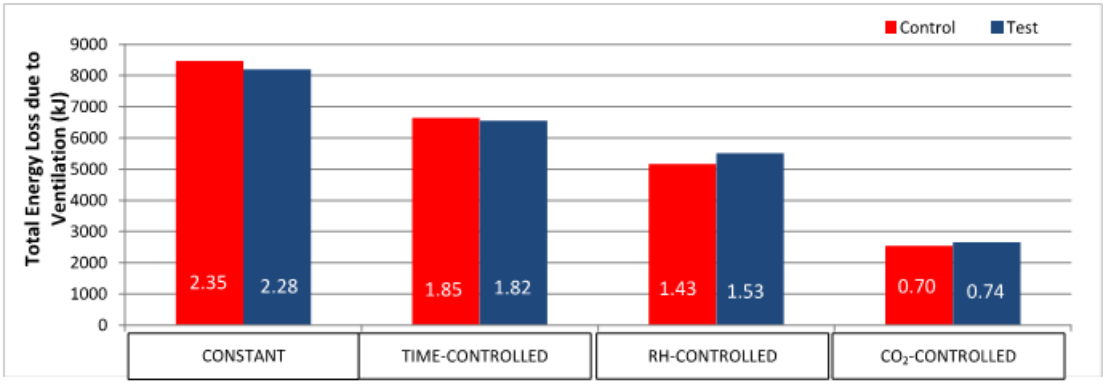

Figure 13: Total energy loss (heating and cooling) due to ventilation for a duration of 28 hours under test cases. Values indicated on each bar are energy loss in kilowatt-hours.

Amongst the active moisture management measures, time-controlled ventilation is most effective in maintaining both the test building and the control building's relative humidity levels below the 65%, close to the acceptable range. However, in practice, time-controlled ventilation may not be as successful as in field testing due to uncertainty in the duration and frequency of peak moisture loading of occupants.

Time-controlled ventilation may be a viable solution in spaces where peak moisture loading can be accurately predicted, such as a commercial kitchen, gymnasium, theatre, or spa. In a residential setting where moisture loading is a function of the occupants' density, daily habits, presence, and other factors that cannot be accurately predicted in design, it may not successfully address moisture issues. This is the case in the 'Reference Building'.

An alternative to time-controlled ventilation in application can be motion detector sensing ventilation systems. These systems may can detect the presence of occupants and boost when occupants are active and present. They also provide savings benefits in that the ventilation demand can be lowered when occupants are not home.

RH-controlled ventilation is effective at maintaining CO_2 levels at acceptable levels for indoor air quality, but fails to maintain relative humidity levels below acceptable levels.

CONCLUSION

In general, the following conclusions can be drawn from the results:

1) Based on Figure 13, the time-controlled ventilation scheme results in 20% energy savings in both the test and control buildings in comparison to constant ventilation. This energy saving is achieved without compromising indoor humidity levels, especially in the test building where moisture buffering potential allows regulation of humidity peaks. Conversely, indoor air quality in terms of indoor CO_2 levels are most adversely affected under time-controlled ventilation, remaining above 1000 PPM for approximately 50% of the monitoring period.

2) RH-controlled and CO_2-controlled ventilation show improved ventilation energy savings in comparison to the latter two test cases. RH-controlled ventilation results in approximately 35% ventilation heating and cooling energy savings, and CO_2-controlled ventilation results in

approximately 70% savings compared to constant ventilation for both buildings. However, it should be noted that these figures are based on test data during the warmer months of June and July, which can effectively reduce overall ventilation heat loss. RH-demand and CO_2-demand ventilation schemes produced the best indoor air quality, with CO_2 levels never exceeding 1000 PPM during the monitoring period. However, indoor humidity levels were generally above acceptable levels for thermal comfort.

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