Technical Bulletin

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Air Quality in Multi-Unit Residential Buildings

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Introduction

Ventilation in Multi-Unit Residential Buildings (MURBs) is typically provided by a pressurized corridor system (Figure 1). This method uses a common make-up air unit to provide air to the corridors of each floor and create a positively pressurized space. The intent of the design is for the air from the corridors to pass through the suites to the exterior driven by this pressure difference and the use of exhaust fans. Though this system design is pervasive throughout North America there is considerable evidence that the ventilation design does not perform as intended, resulting in poor indoor air quality and occupant comfort complaints.[1]

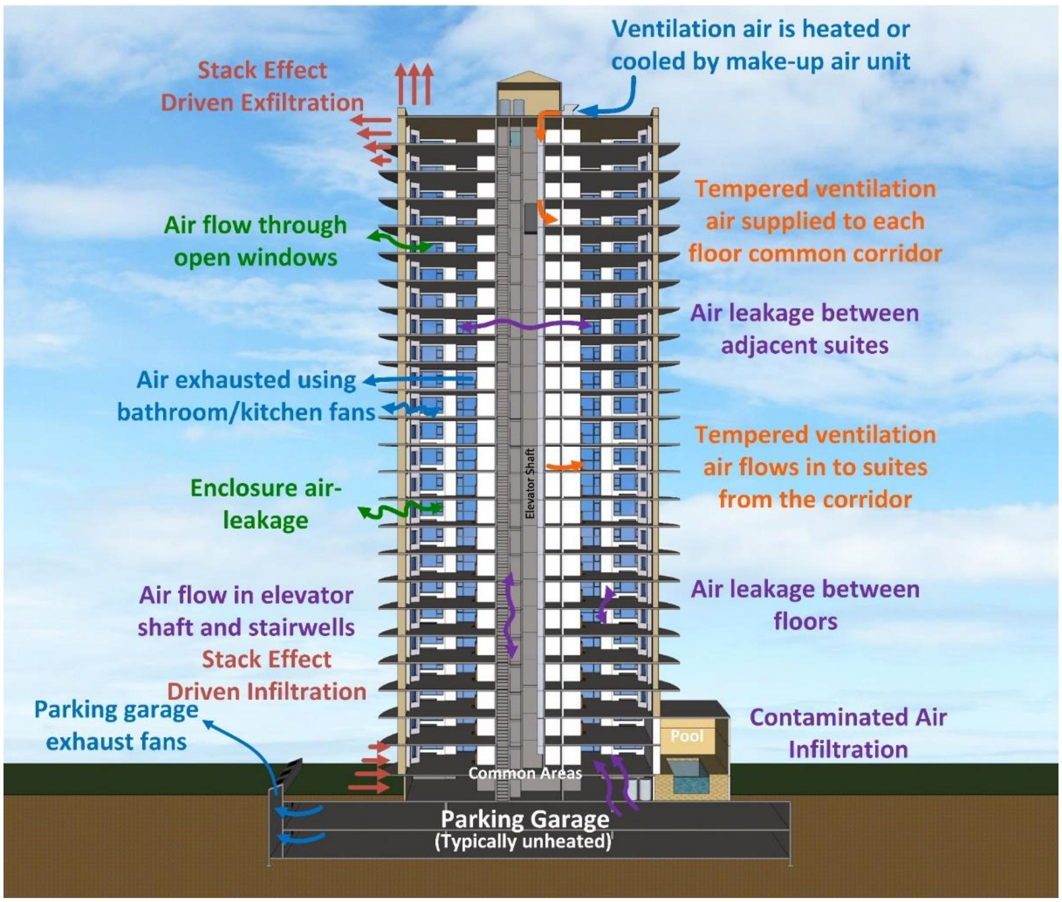

Figure 1: Overview of components of airflow and ventilation in a multi-unit residential building

Indoor Air Quality

Indoor air quality is an important factor in determining the health and comfort of a building occupant. Air quality is measured based on the concentration of pollutants such as fine particulate matter (PM2.5), carbon dioxide (CO_2), and formaldehyde, among many others.

[1] Ricketts, L. 2014. "A Field Study of Airflow in a High-rise Multi-unit Residential Building". MASc Thesis. Civil Engineering Dept., University of Waterloo.

Exposure to these pollutants can cause adverse health effects and recommended exposure limits exist for many pollutants.[2,3]

CO_2 is produced by people when they exhale. It is an easily measureable pollutant that is often used as an indicator of indoor air quality. Low CO_2 concentrations indicate that fresh air is being provided to space in sufficient quantities to remove the build-up of many common pollutants, and particularly bioeffluents. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) provides guidance for the design of clean indoor environments in ASHRAE Standard 62.1 - Ventilation for Acceptable Indoor Air Quality[4] and the Indoor Air Quality Guide.[5] The recommended design airflow rates of the prescriptive design procedure in ASHRAE 62.1 are provided to control CO_2 concentrations to 700ppm above outdoor conditions which provides indoor concentrations of ~1100ppm. Recent research indicates that CO_2 itself may be considered an indoor pollutant that impairs a person's decision making abilities at levels previously considered to be below safe limits. In laboratory studies, moderate declines in decision making performance were found at 1000ppm and significant declines were found at 2500ppm.[6] The control of CO_2 and other indoor pollutants is an important aspect of a healthy building.

Another key aspect of the quality of the indoor environment is the temperature and relative humidity of the air. Relative humidity indicates the percentage of moisture in the air compared to the saturation moisture content of air at that temperature. The building HVAC systems should be capable of controlling the relative humidity within a space to maintain comfort for occupants. The human comfort range for relative humidity strongly depends on the individual and the surroundings but is generally within the range of 25-60%.[7,8] Relative humidity levels below this range can cause irritation and levels above may cause feelings of discomfort.

Relative humidity is also important for health considerations. Moisture in the air will condense on surfaces with temperature below the dew point temperature of the surrounding air. This moisture source, along with others, will result in deteriorating indoor air quality. Dampness in the indoor environment has been identified as a hazard to human health by the WHO due to the prevalence for promoting biological growth.[9] Moisture on surfaces can promote mould and fungal growth within a building leading to exposure and health impacts. Moisture and dampness in homes are correlated with significant increases

[2] Health Canada, 2015. "Residential Indoor Air Quality Guidelines". Government of Canada. http://healthycanadians.gc.ca/healthy-living-vie-saine/environment-environnement/air/guidelines-lignes-directrices-eng.php#a1
[3] WHO, 2000. "Air Quality Guidelines for Europe, 2nd Edition". World Health Organization Regional Publications, European Series No. 91. World Health Organization, Regional Office for Europe, Copenhagen, Denmark. http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf
[4] ASHRAE, 2013. "ANSI/ASHRAE Standard 62.1-2013 Ventilation for Acceptable Indoor Air Quality". American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.
[5] ASHRAE, 2009. "Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning". American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.
[6] LBNL, 2013. "Is CO2 an Indoor Pollutant? Higher Levels of CO2 May Diminish Decision Making Performance". Lawrence Berkeley National Laboratory. http://eetd.lbl.gov/sites/all/files/lbnl-6148e-is_co2_an_indoor_pollutant_v3.pdf
[7] ASHRAE, 2013. 2013 ASHRAE Handbook: Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, 2013.
[8] Lstiburek, J. 2002. "Research Report – 0203 – Relative Humidity". Building Science Corporation.
[9] WHO, 2009, "WHO Guidelines for Indoor Air Quality: Dampness and Mould". The WHO European Centre for Environmental Health, Bonn, Germany.

in respiratory symptoms such as coughing and wheezing[10] as well as increases in the occurrence of Bronchitis and respiratory infections.[11] The HVAC system and building envelope should be designed to control dampness within the building to promote a healthy environment.

Monitoring of IAQ in Multi-Unit Residential Buildings

Continuous monitoring of temperature, relative humidity, and CO_2 concentrations within a high-rise multi-unit residential building can be conducted to determine the air quality throughout the building. Comparison of the air quality with measurements of airflow can be used to identify deficiencies and potential solutions. Air quality issues include stuffiness or odours due to inadequate ventilation, uncomfortable temperatures as a result of warm surfaces or cold drafts, or health issues due to contaminant build-up or mold growth.

RDH has investigated a number of performance problems in MURBs throughout North America. A case study building is used here as an example of the potential for indoor air quality monitoring to be used to identify problem areas with building performance. The case study building is a high-rise MURB with a pressurized corridor and intermittent exhaust within the suites. The building layout consists of three suites per floor typically occupied by two residents. The methods and findings are applicable to other MURBs throughout North America.

Air Quality Differences

Measurements of CO_2 concentrations within a building can identify areas of poor indoor air quality and potential improvement to the operation. A sample of CO_2 measurements shown in Figure 2 highlights the variability of concentrations within a suite occupied by two residents over a three week period during the heating season. CO_2 varies significantly with time due to changes in occupancy patterns and airflow rate. Variations are also seen between different rooms in the suite indicating variability of the ventilation system effectiveness.

[10] Fisk et al., 2007. “Meta-analyses of the associations of respiratory health effects with dampness and mold in homes”. Indoor Air 17: 284-296.
[11] Fisk et al., 2010. “Association of residential dampness and mold with respiratory tract infections and bronchitis: a meta-analysis”. Environmental Health 9: 72.

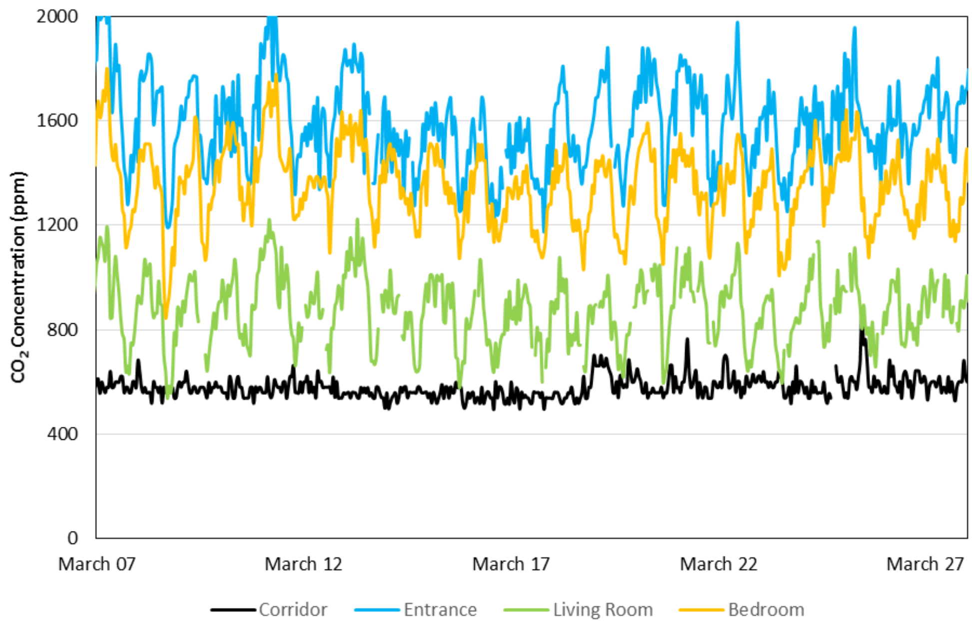

Figure 2: CO_2 variations within a representative suite over a 3-week period

The average air quality throughout the year of measurements within each suite on three lower and three upper floors of the building is also compared in Figure 3. Significant air quality differences are found between neighbouring suites indicating that the ventilation needs of all individuals within the building are not being met. In some cases the CO_2 concentrations differ by a factor of two between adjacent suites on the same floor. The annual average CO_2 concentrations are found to exceed the ASHRAE design guidelines of 1100ppm for some of the suites in the building while others appear to have consistently low levels (<700ppm).

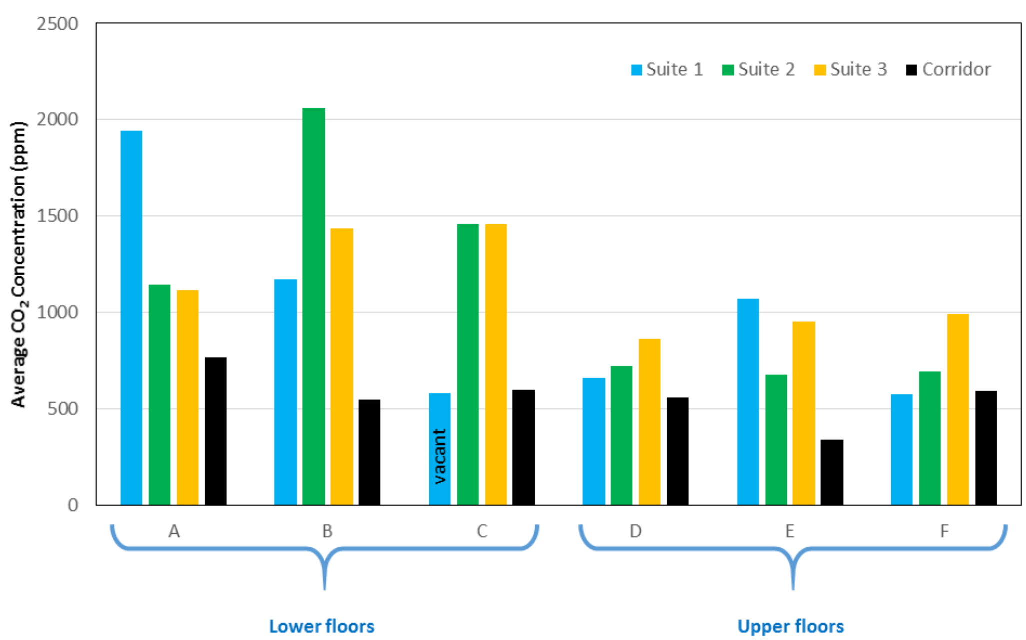

Figure 3: Air quality variations between suites in a case study MURB

The average annual CO_2 concentrations are compared to the annual average airflow rate from the corridors into the suites on each of the six floors in Figure 4. The suites with high ventilation rates are found to have low CO_2 levels (good air quality), while suites with low flow rates have high CO_2 concentrations (poorer air quality). The disparity in flow rate and indoor air quality was found to be divided by location in the building with upper floors having better air quality than lower floors. This indicates an imbalance of air supply servicing different spaces. The annual average CO_2 of all suites on the lower floors is found to exceed the design guidelines of 1100ppm while the upper floors are under this threshold.

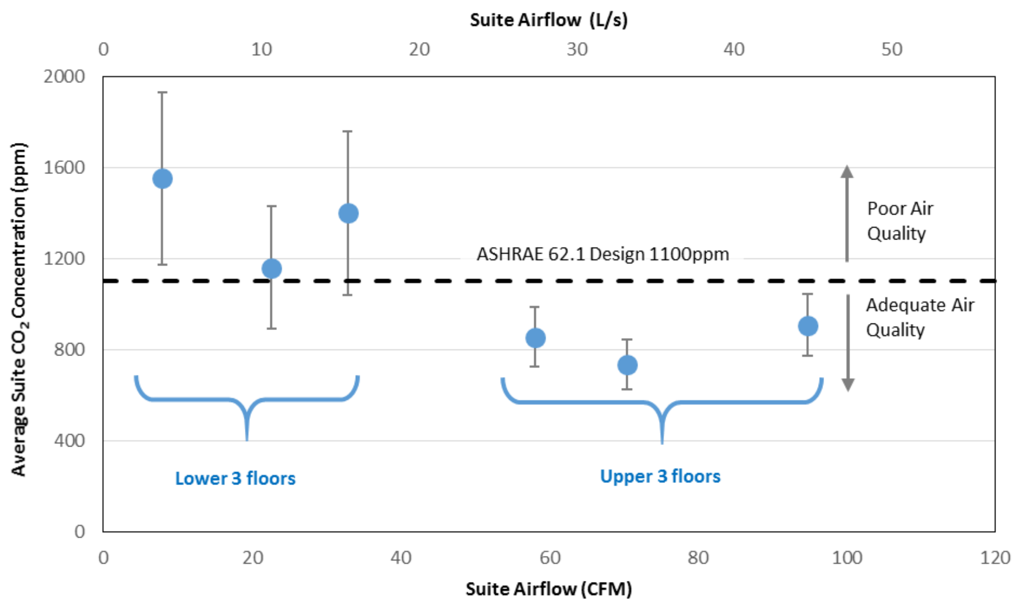

Figure 4: Air quality differences between floors due to uneven airflow distribution

Meeting Air Quality Standards

The CO_2 monitoring shows that many areas in the case study MURB do not meet design indoor air quality guidelines based on an annual average. The fraction of the time that the measured CO_2 concentration for suites on each floor of the study exceeded a specified CO_2 concentration is shown in Figure 5. The average concentration in suites on each of the upper three floors rarely exceeds the design guideline (1100ppm). However, the average CO_2 concentration in suites on the lower three floors exceeds design levels between 64% and 91% of the time. Improvements in the ventilation system could provide better air quality to suites throughout this MURB.

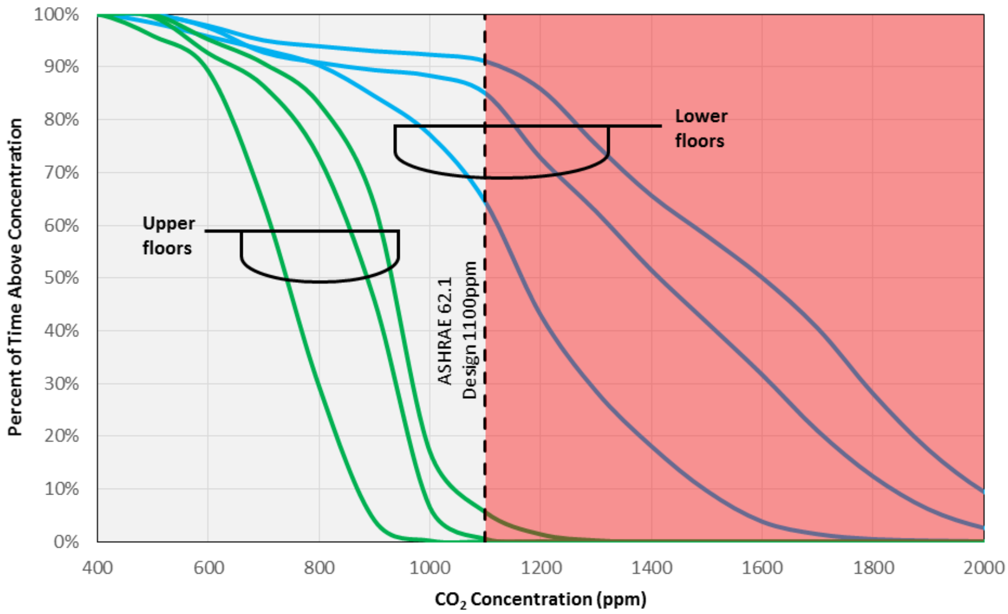

Figure 5: Fraction of time the average suite CO_2 level is above a given concentration

Monitoring of Moisture and Temperature in Multi-Unit Residential Buildings

Condensation and Fungal Growth

Dampness is present in 10-50% of buildings around the world[12] and is a common complaint amongst building owners in wet climates such as Vancouver. Previous condition assessments by RDH have shown a correlation between indoor dew point temperature and the prevalence of fungal growth and condensation in apartment suites (Figure 6) during the heating season. The findings show that during the winter months a dew point temperature of greater than approximately 10˚C (equivalent to a 21˚C air temperature and 50% Relative Humidity) is likely to result in condensation and/or fungal growth on the interior of windows and other cold surfaces.

[12] WHO, 2009, "WHO Guidelines for Indoor Air Quality: Dampness and Mould". The WHO European Centre for Environmental Health, Bonn, Germany.

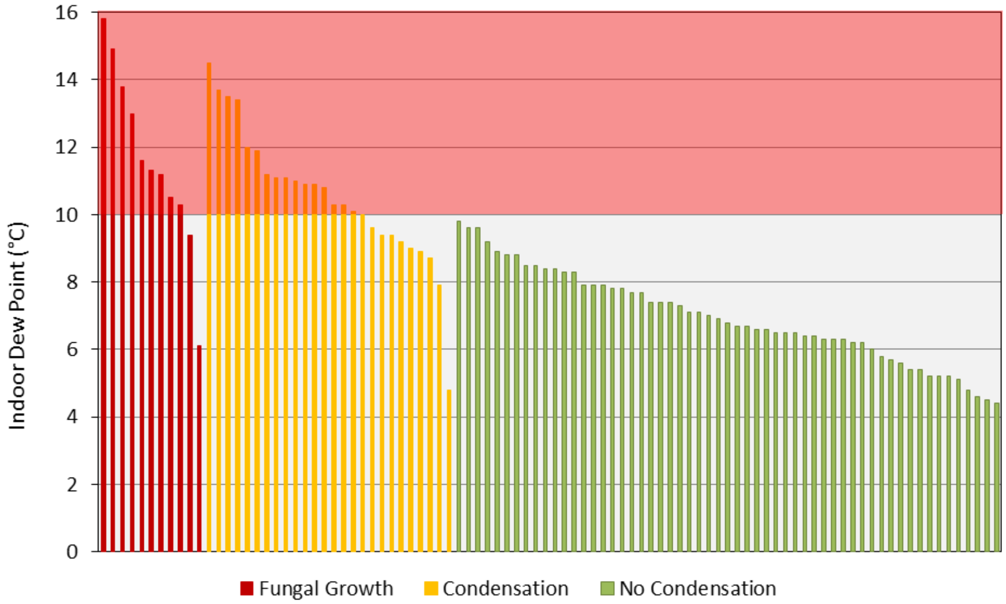

Figure 6: Indoor dew point temperature measured in suites with fungal growth, condensation, or no condensation during the heating season in Vancouver, BC

Figure 7: Condensation and mold growth on interior window surfaces

Continuous monitoring of dew point temperature can be used in conjunction with the airflow and CO_2 measurements to identify potential air quality and health concerns. Figure 8 presents the fraction of the time the dew point in the entrance area of each suite in the study building was above the indicated value. There is a clear separation between the suites on upper floors and the suites on lower floors. Upper suites have a dew point temperature in excess of 10°C less than 30% of the time compared to 40-95% of the time for lower suites indicating that fungal growth is more likely in the lower more poorly ventilated suites.

A similar comparison can be made between areas within suites as shown in Figure 9. The corridor and entrance areas of the three suites have dew point temperature above the 10°C threshold for significant portions of time (similar to Figure 8). The master bedrooms and living rooms have even higher dew point temperatures relative to the associated suite entrance. These results are similar for other floors in the building. The higher dew point temperature in these perimeter areas results in an even higher probability of condensation due to the window locations and can be a significant source of poor air quality in the suites on lower floors.

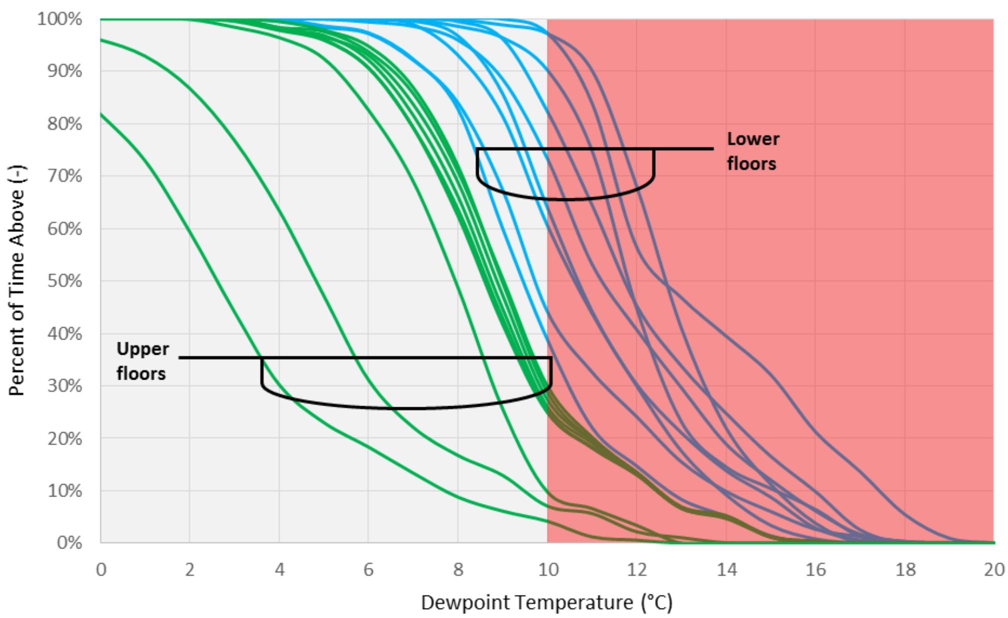

Figure 8: Percentage of time the dew point temperature is above a given threshold during the heating season in suite entrance doorways

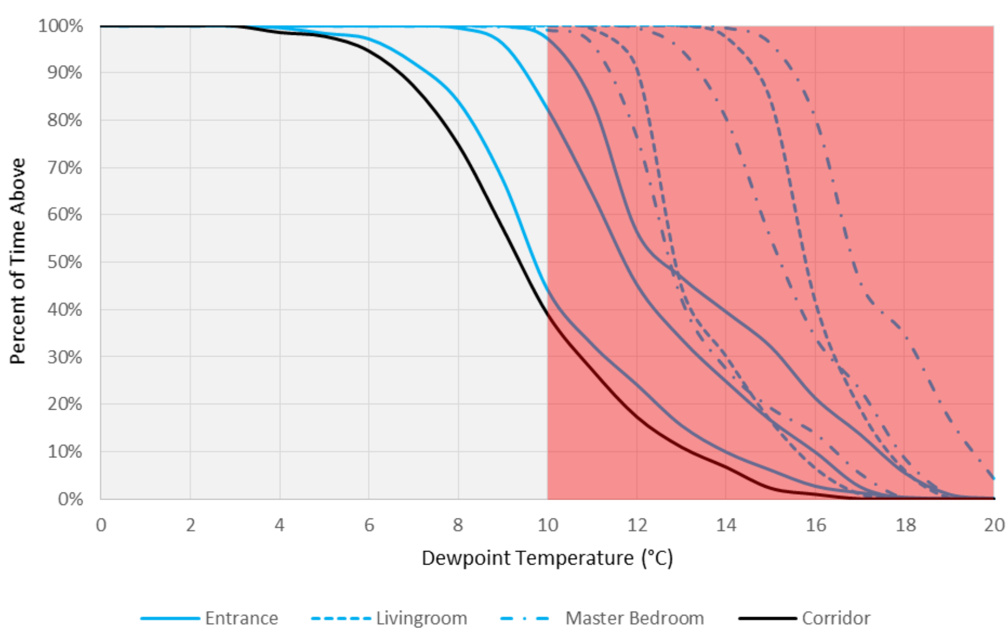

Figure 9: Percentage of time the dew point is above a given threshold during the heating season throughout suites on a lower floor

Indoor Comfort

Conditions for indoor comfort are outlined in ASHRAE 55-2013 Thermal Environmental Conditions for Human Occupancy.[13] Comfort is based on the interaction of a wide range of parameters including air and surface temperature, humidity, clothing, location, and air speed. Indoor thermal comfort is highly subjective and the desired range of indoor temperatures can vary significantly from person to person or buildung to building. Buildings are typically designed around a range of acceptable relative humidity and temperature ranges that can be used to approximate the comfort compliance in the absence of complete knowledge of the indoor conditions.

The relative humidity in the study suites can be used to identify potential comfort issues if it is outside the range of 25-60%. The fraction of time the RH in each suite is above a specified value is plotted in Figure 10. A clear distinction between the suites on upper and lower floors can again be seen but most suites within the building, regardless of floor, showed relative humidity within the acceptable range for the majority of the time. This indicates that though the higher relative humidity may result in condensation and fungal growth in the lower suites (Figure 10), the occupants are not likely to perceive a comfort issue related to the moisture in the air.

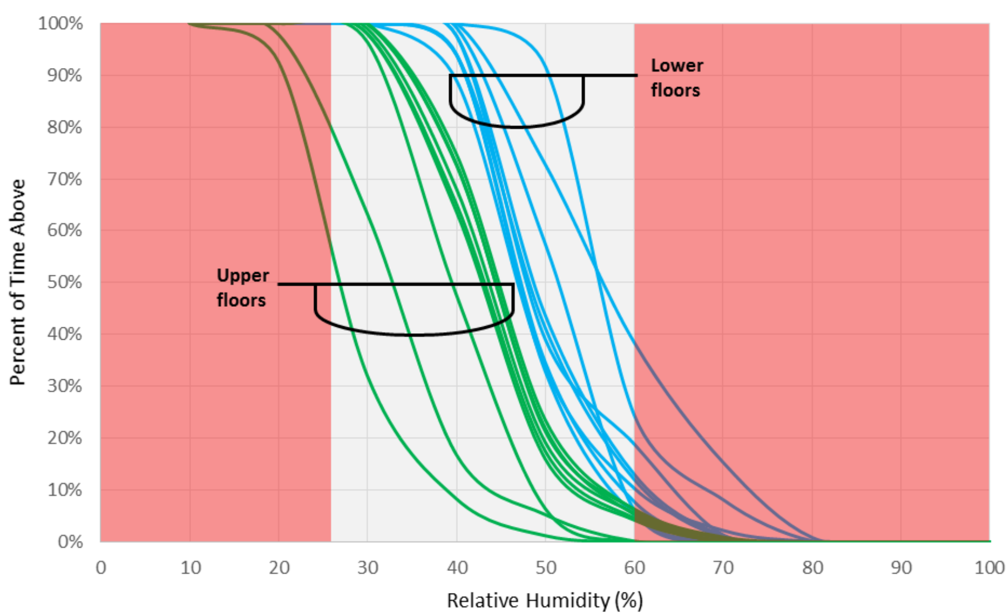

Figure 10: Percentage of time relative humidity is above an indicated threshold during the heating season

The representative indoor temperature comfort range is 21˚C to 25˚C for typical design conditions.[14] The percentage of time the air temperature in the entrance of suites in lower floors (blue) and upper floors (green) is greater than a specified value is shown in Figure 11. Unlike relative humidity and dew point, there is no distinct difference between the temperature in suites on upper and lower floors. Additionally, the temperature is generally

[13] ASHRAE, 2013. "ANSI/ASHRAE Standard 55-2013 Thermal Environmental Conditions for Human Occupancy". American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.
[14] ASHRAE, 2013. 2013 ASHRAE Handbook: Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, 2013.

controlled to within the typical comfort range for the majority of time in the majority of suites indicating that comfort is not likely to be a significant concern for the occupants.

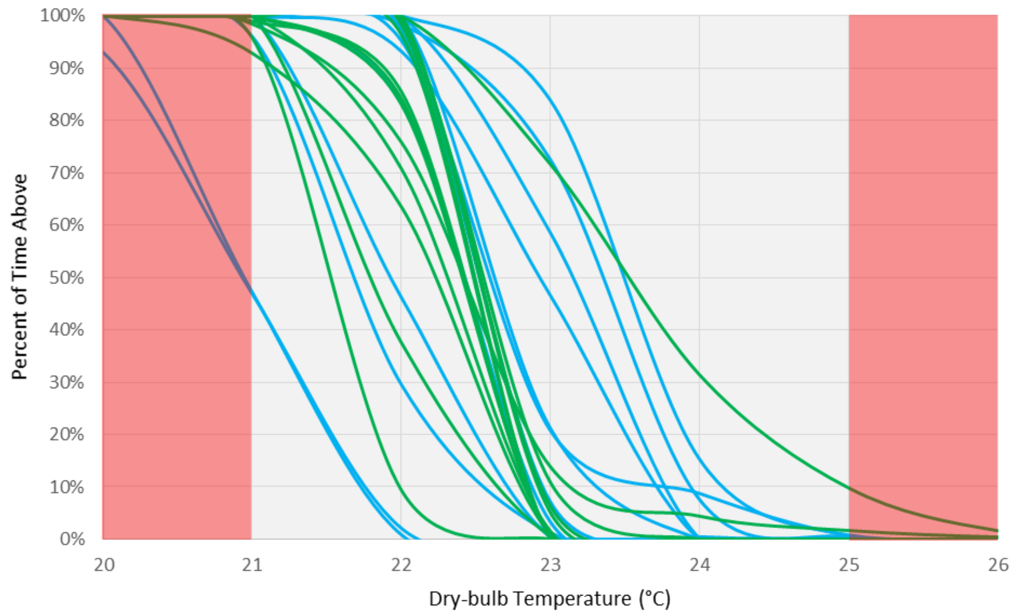

Figure 11: Percentage of time dry-bulb temperature is above an indicated threshold during the heating season. (Suites in upper floors are presented in green and lower floors in blue).

Conclusions

Air quality issues are common in many buildings and may lead to detrimental health effects among occupants. Continuous monitoring of a case study MURB showed elevated CO_2 concentrations in suites on lower floors that were often in excess of current ASHRAE design guidelines. Measurements of temperature and relative humidity also showed that the suites on lower floors had elevated dew point temperatures associated with fungal growth and condensation for a significant fraction of the time during winter months. The air quality issues were linked to poor ventilation air distribution within the building. The results at this case study building are likely representative of conditions of many low to high-rise multi-unit residential buildings ventilated with pressurized corridor systems.

What else can we measure?

Carbon dioxide, temperature, and relative humidity are all common measurement tools for determining air quality in a building, but other pollutants that have been determined to be harmful may be present and can also be measured. These pollutants will often be controlled in different manners from CO_2 and may be present in high quantities even in suites where CO_2 is well controlled.

- **Volatile Organic Compounds (VOCs)** – Volatile organic compounds are a family of gas phase chemicals that contain carbon and hydrogen. They have a variety of sources such as cleaning products, building materials, and cigarette smoke. Many

VOCs are known to be toxic such as Benzene and Formaldehyde.[15] Specific thresholds for a combination of VOCs have not been developed.[16]

- **Carbon Monoxide (CO)** – Carbon Monoxide is a gas generally produced as a bi-product of incomplete combustion. It has many potential sources both indoors and outdoors including gas appliances and cars. Indoor carbon monoxide concentrations should be kept below 10ppm.[17]
- **Ozone (O_3)** – Ozone is a colourless gas that is generated outdoors by cars and industrial sources. Exposure to elevated ozone can cause decreased lung function. Indoor ozone concentrations should be kept below 20ppb.[18]
- **Particulate Matter (PM2.5)** – PM2.5 is the mass of all airborne particles with a diameter of less than 2.5μm. PM2.5 is generated both indoors and outdoors by many sources such as household chores, cooking, and vehicle exhaust. Exposure to elevated levels of PM2.5 is associated with increased risk of cardiovascular and respiratory health impacts. There is no recognized lower exposure limit for PM2.5 and levels should be maintained as low as possible.[19]

How can we improve air quality?

Indoor air quality within a building can often be improved through a number of different means. Increasing the amount of clean ventilation air reaching an area can effectively reduce the build-up of both gas pollutants and particulate matter. Increases in ventilation may be achieved through improvements to the existing system, such as a rebalancing of airflow, or a retrofit to change the system design, such as replacement of a pressurized corridor system with new suite-level dedicated ventilation (Figure 12). Other potential methods to improve air quality include prevention of local outdoor sources, such as idling vehicles near ventilation intake, removal of indoor sources by using localized exhaust over cooking sources, or active removal of particles using an air filtration system. The choice of intervention depends on the site condition and can be determined by measuring air quality within the building.

[15] WHO, 2010. "WHO Guidelines for Indoor Air Quality: Selected Pollutants". The WHO European Centre for Environmental Health, Bonn, Germany.
[16] ECA-IAQ, 1997. "Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations". European Collaborative Action – Indoor Air Quality & Its Impact on Man. Working Group 13. European Commission Joint Research Centre – Environment Institute, Luxembourg.
[17] Health Canada, 2010. "Residential Indoor Air Quality Guideline – Carbon Monoxide". Government of Canada.
[18] Health Canada, 2010. "Residential Indoor Air Quality Guideline – Ozone". Government of Canada.
[19] Health Canada, 2012. "Guidance for Fine Particulate Matter (PM2.5) in Residential Indoor Air". Government of Canada.

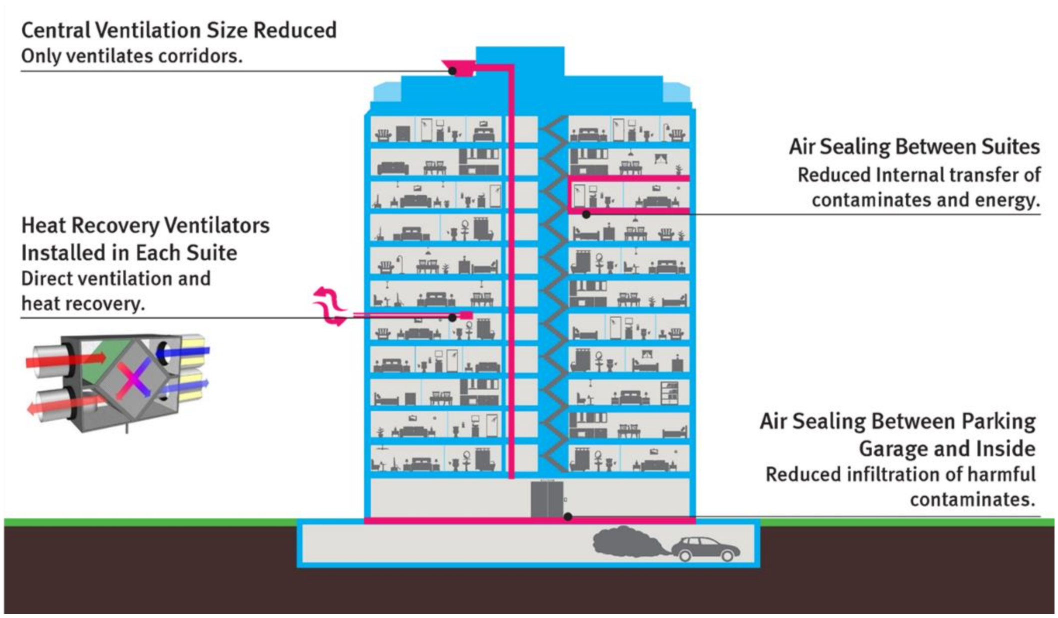

Figure 12: Improved ventilation strategy for MURBs

For additional information on this and other topics, please visit our website, rdh.com, or contact us at contact@rdh.com.

Additional Resources

- ASHRAE, 2009. Indoor Air Quality Guide – Best Practices for Design, Construction, and Commissioning. American Society for Heating, Refrigerating, and Air-Conditioning Engineers. Atlanta, GA.
- Ricketts, L and Straube, J, 2014. A field study of Airflow in Mid to High-Rise Multi-Unit Residential Buildings. 14th Canadian Conference on Building Science and Technology, Toronto, ON. http://rdh.com/wp-content/uploads/2015/01/CCBST-2014-A-Field-Study-of-Airflow-in-High-Rise-Multi-Unit-Residential-Buildings-LR-JS.pdf
- CMHC, 2003. Ventilation Strategies for Multi-Unit Residential Buildings: Performance Requirements and Alternative Approaches. https://www03.cmhc-schl.gc.ca/catalog/productDetail.cfm?cat=37&itm=41&lang=en&fr=1440015343246