Healthy High-rise: Ventilation Issues and Innovations

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Abstract: Over the past several years many issues have come to light that have highlighted the need for improved ventilation in multi unit residential buildings (MURB's). High-rise buildings, for example, are all too often connected with poor indoor air quality. When looking at this issue from the perspective of urbanism and the trend to increasing the density of our urban centres, there is a dramatic need to address the ventilation issue in MURB's. To enhance the success of the 'Open Living' concept, solutions that improve the possibility for the future adaptations of the use of space in buildings need to be developed.

Recent research by CMHC has shown that many existing ventilation systems do not perform as intended due to two main factors: lack of envelope air tightness and the strong stack effect in tall buildings. As a result, the extent of ventilation in suites ranges from over-ventilated to under ventilated, with units often receiving stale ventilation air from other parts of the building during the heating season when windows are closed.

In response to the growing recognition of the need for improved ventilation in homes, the federal government department Natural Resources Canada (NRCan) and several Canadian manufacturers have teamed up to develop a new category of products that efficiently provide residential space heating, water heating and ventilation with heat recovery for low rise residential buildings under the trade name of eKOCOMFORT. The great versatility of the eKOCOMFORT system, demonstrated in the early testing of the product, initiated a move by the Canada Mortgage and Housing Corporation (CMHC) to begin testing of this new product in high-rise applications.

This paper looks at the issue of ventilation in high-rise residential buildings, examining the advanced combination heating and ventilation system and the potential for application of this system in the high-rise residential market.

Keywords: Ventilation, Heating Systems, Indoor Air Quality, Innovation

1. INTRODUCTION

Many issues have come to light over the past several years that have highlighted the need for improved ventilation in multi unit residential buildings (MURB's). High-rise buildings, for example, are all too often connected with poor indoor air quality. When looking at this issue from the perspective of urbanism and the trend to increasing the density of our urban centres, there is a dramatic need to address the ventilation issue in MURB's. To enhance the success of the 'Open Living' concept, solutions that improve the possibility for the future adaptations of the use of space in buildings need to be developed.

In Canada, ventilation in high-rise MURB's is delivered through corridor air systems. In these systems, corridors are pressurized to supply air to individual residential units, relying in on gaps around and the operation of the entrance doors to each unit to deliver air to the unit. Research at the Canada Mortgage and Housing Corporation has consistently demonstrated that this system does not work. Compounding this, as construction of building envelopes improves in air tightness, the amount of fresh air entering units will decrease, resulting in a further reduction in indoor air quality.

2. THE PROBLEM

Most high-rise residential buildings are not equipped with mechanical ventilation systems, which supply air to occupants. The typical corridor pressurization systems are installed to control the transfer of odours between suites and provide makeup air to replace air exhausted by kitchen and bathroom exhaust fans. The design assumes that ventilation air for occupants will be supplied by natural ventilation through operating windows, by infiltration through the building enveloped, and in some cases by makeup air provided by the corridor pressurization system.

Recent research by CMHC has shown that these corridor pressurization systems do not perform as intended due to two main factors: lack of envelope air tightness and the strong stack effect in tall buildings. As a result, the extent of ventilation in suites ranges from over-ventilated to under ventilated, with units often receiving stale ventilation air from other parts of the building during the heating season when windows are closed.

Excessive infiltration rates, due to wind and stack induced infiltration through leaks in the building envelope and between floors, are also common. Common locations where excessive ventilation occurs include lower suites subjected to high stack pressures on cold winter days, and windward facing suites on windy days. Insufficient ventilation rates commonly occur on upper floors and on leeward facing suites die to inhibited or reversed ventilation airflow.

A number of other problems are also common in high-rise residential mechanical ventilation systems. In many instances, exhaust fans are not capable of moving a sufficient amount of air, and frequently their operation is so noisy that occupants do not use them. Back drafts and noise can also result in occupant tampering with the exhaust vent in order to reduce the noise problem, often with the result of significantly reducing its operating capacity.

Finally, the energy costs associated with inefficient fan operation and re-heating of ventilation air are significant in many buildings. Recovery of heat from air exhausted from the building is rare.

3. A NEW PRODUCT

In response to the growing recognition of the need for improved ventilation in homes, the federal government department Natural Resources Canada (NRCan) and several Canadian manufacturers have teamed up to develop a new category of products that efficiently provide residential space heating, water heating and ventilation with heat recovery under the trade name of eKOCOMFORT.

Continuous ventilation with heat recovery is required to improve indoor air quality for home occupants. In the 1980's, Canada developed an energy-efficient housing program with better insulated and air sealed homes that had continuous ventilation. This lead to the development of the Canadian Heat Recovery Ventilator (HRV) industry, an industry that now provides HRV's for both domestic and export markets. While HRV's have become more widespread in their use, the HRV market share has been limited by the costs associated with production, distribution, installation and operation. By integrating the HRV functions into heating products, there is potential to reduce all of these costs. The eKOCOMFORT Project was developed to speed the development and deployment of such products.

The key technical innovation is the integration of a wide number of components into a factory engineered system with a single warrantee (rather than a number of components that are put together in the field with individually warrantees). Advanced controls are required to optimize the products when they are fulfilling more than one function simultaneously. Many components have not previously been part of a rated package and have had to be upgraded to improve efficiency and capacity in order to meet the performance specifications. In comparison to a typical installation of existing equipment, integrating ventilation into the space heating product has enabled the electrical cost of providing and distributing fresh air to be cut by a factor of more than five.

The concurrent development of multiple products and infrastructure has reduced manufacturer risk and enabled each manufacturing group to proceed. Each of the manufacturing teams view the other teams commercializing the same type of product as a benefit as it legitimizes their product in the marketplace. It has also speeded up the creation of testing and standards that allow the products to be deployed in various jurisdictions. As each of the manufacturing groups has based their product on different base technologies, they have been willing to help each other overcome specific technical and logistical problems. In other words, they see traditional equipment as the main competition rather than each other. The approach has also enabled government to reduce its' risk as no one manufacturing group is vital to the success of the project. Five manufacturing teams are each commercializing a product that meets the same set of minimum performance specifications for these functions.

3.1. Product Testing

To fully assess their performance, these products are undergoing field trials in single-family homes located in Ontario and Nova Scotia. To carry out the field trials NRCan enlisted the support and expertise of the Canada Mortgage and Housing Corporation (CMHC), Canada's nation housing agency. The field trials, now ongoing, include extensive monitoring of various aspects of the heating and ventilation components of the system. In addition, a complete energy audit is carried out each building where one of the eKOCOMFORT units is being installed. This included carrying out heat loss calculations and undertaking an air tightness analysis using a door fan. The standard monitoring package and data acquisition program for the field assessment project consisted of:

- One Campbell Scientific CR10X data logger
- 11 thermocouples
- Two Kamstrup energy meters
- One in-line electricity meter with pulse output
- A fuel-valve timer and isolating relay to monitor burner on-off operation
- Status relays to signal control/operating status to the data logger

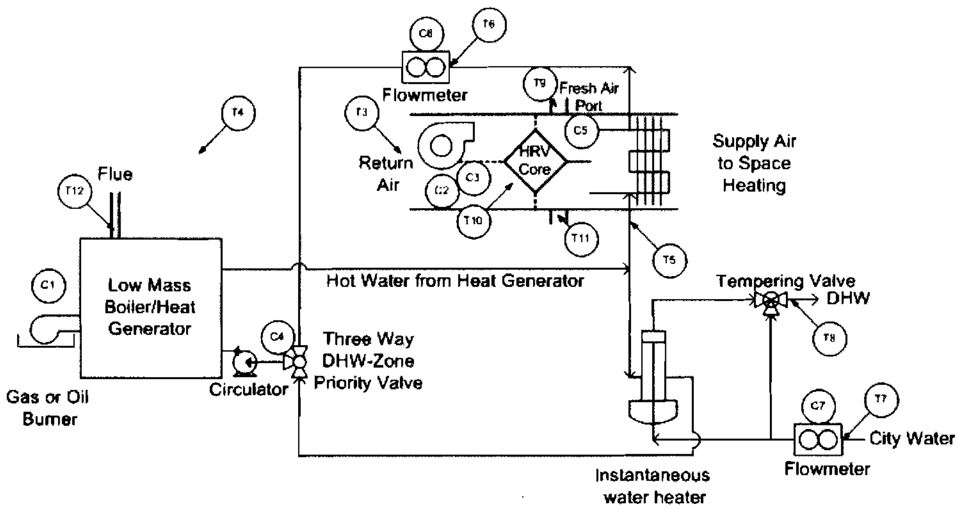

Figure 1: Simplified Monitoring Schematic for Vebteck Site

The integrated system that is installed at this site is comprised of:

- A low mass, low water volume boiler/heat generator

- A natural gas burner
- An airhandler/fancoil with integral HRV section
- An instantaneous DHW heat exchanger with an anti-scald mixing valve that can be adjusted to the user's preference.

The unit is designed to operate as follows:

- Burner on-off operation is controlled by an immersion aquastat installed in the water-filled section (~11 US Gallons) of the heat generator.
- The heat generator circulates high-temperature water directly to the space-heating coil or to the instantaneous water heater module using a three-way valve to direct hot water flows as needed.
- A requirement for domestic water heating is detected by a thermistor installed in the potable-water side of the instantaneous water heater.
- A conventional thermostat located in the heating zone signals a call for space heating.
- Domestic water heating has priority in the event of a simultaneous requirement for both space heating and DHW heating.
- When there is no call for either space heating or water heating, the three-way valve defaults to the domestic water heating position, but the circulator is shutoff.
- Because of the need to quickly respond to a DHW draw, and to avoid excessive condensation in the heat generator, the heat generator is designed to remain hot during standby.

During the first phases of the product installations and testing, the versatility of the systems and their adaptability for a wider variety of applications offered some interesting possibilities. In one installation, for example, the integrated system was installed been to supply both heat, through a combination of forced air and radiant heating zones in each suite, and hot water to the main house and a 'granny flat'. The versatility and capacity of the unit to handle this variety of functions pointed to its potential for use in other applications (Figure 2)

3.2. Product Adaptations

Improved mechanical ventilation systems for high-rise applications are highly needed to provide clean tempered fresh air to the building occupants. Increasingly in our tight and better-insulated buildings, mechanical ventilation becomes the primary mechanism for exhausting excess humidity, odours and pollutants from within suites and common areas of the building. When properly designed, installed and operated, mechanical systems can be the most efficient, secure and economically viable method of ensuring good IAQ in multi-unit residential buildings. They allow the occupant control over the quality of indoor air in the suite and should accommodate the operation of windows in suites.

In response to the need for improved ventilation in high-rise residential buildings and in the growing condominium market, the design of mechanical ventilation systems for individual apartment suites is now being developed. The great versatility of the eKOCOMFORT system, demonstrated in the early testing of the product, initiated a move by the Canada Mortgage and Housing Corporation (CMHC) to begin testing of this new product in high-rise applications.

3.3. Compartmentalization or not

In examining the advantages and disadvantages of different systems, we begin with a comparison of centralized and in-suite systems. Centralize systems, the primary system utilized in Canada; offer the advantage of having one point of control and maintenance. This offers the added advantage of being able to incorporate a heat recovery system at this one central location (although at present this is not commonly done). With minimum space requirements, these systems are often preferred by apartment dwellers.

Individual suite ventilation systems offer a number of advantages. They allow much more control of the temperature and the ventilation in each suite, and are easier to balance, allowing for more even temperatures to be delivered throughout the suite. In addition to comfort, this can reduce the airflow into the suite through the exterior walls and from the adjacent suites or common areas. With an increasing awareness and concern over indoor air quality and ventilation, it seems to be clear that improvements in this area can be most effectively gained with a system that supplies air directly to each suite.

To make this type of system to work most effectively, construction details that maximize the air tightness of the individual suite need to be carried out. There are several details that can contribute to how well a system like this performs. In some cases, an airtight separation of individual floors can be carried out. This will minimize the pressure difference across exterior walls giving each floor a reduced gradient design condition and providing the opportunity to heat and ventilate each floor individually. In other cases individual suites can be compartmentalized and ventilated by individual units. This technique can reduce or eliminate problems such as odour migration from adjacent units or other problems such as inadequate exhaust flow. In addition this can provide each suite with the opportunity to have separate metering and individual control of their systems. When designing for future flexibility in the use of buildings, careful considerations need to be given to this issue.

An additional motivation for the development of controlled ventilation systems is the potential for reducing energy consumption. In high-rise residential buildings, central systems can be designed to transfer heat through glycol heat loops. For individual suites, reduced energy consumption and improved ventilation can be attained through the use of air-to-air heat recovery units.

3.4. Testing these principles

In response to the need or improved ventilation in multi-unit residential buildings, an innovative combination ventilation and space conditioning (VSC) system has been developed for this market. This unit provides direct fresh air supply by combining a heat recovery ventilator and direct fresh air supply into a fan coil.

Three principle reasons have motivated the development of this unit. These include:

1. The need to improve indoor air quality by reliably, effectively and efficiently introduce ventilation air into apartments
2. The need to reduce energy consumption by providing heat recovery for ventilation air and by allowing corridor air volumes to be reduced
3. The need to allow the sealing of the hall door for better control of odours, smoke and sound.

3.5. Product Description

The layout for the single suite system that incorporates a VSC unit is shown in Figure 3. Typically, this VSC unit provides heating and cooling through the use of a conventional four-pipe high-rise fan coil system with the novel addition of a built-in, plate-type heat recovery ventilator (HRV) core. The HRV pre-heats fresh ventilation air by extracting heat from the outgoing stale air. The main circulation fan of the system draws room air through the return air grille and ventilation air through the HRV core. A two-speed bathroom exhaust fan built into the VSC cabinet draws exhaust air from the bathroom through the stale-air side of the HRV and exhausts it outdoors. As is standard with most HRV units, neither the range hood nor the clothes dryer exhaust through the HRV.

The Fan System

A three-speed fan operating continuously at a one speed is the main circulation fan for this unit. The fan operating speed (low, medium or high) is selected manually at the thermostat. The selected speed is maintained and does not change unless it is manually reset by the occupant.

The exhaust fan is a two-speed fan that provides ongoing ventilation by operating continuously at low speed. The switch to high-speed operation can occur either manually or automatically. A manual wall switch allows the occupant to switch the fan to high speed, while a dehumidistat automatically switches the fan into high speed during showers or other high humidity periods in the residential unit, automatically returning the fan to low speed when the humidity drops to an acceptable level. There is no interconnection between the main circulation fan and the exhaust fan.

To verify and understand more about the performance of this new system field tests were carried out to measure the ventilation performance, and operating characteristics of three installed VSC systems. Testing included carrying out an assessment of the ventilation air quantities delivered under various operating and pressure conditions, electricity consumption of the VSC fan-motor sets, air-tightness testing of the suites and hallways in and around where the VSC's are installed, and depressurization testing of suites.

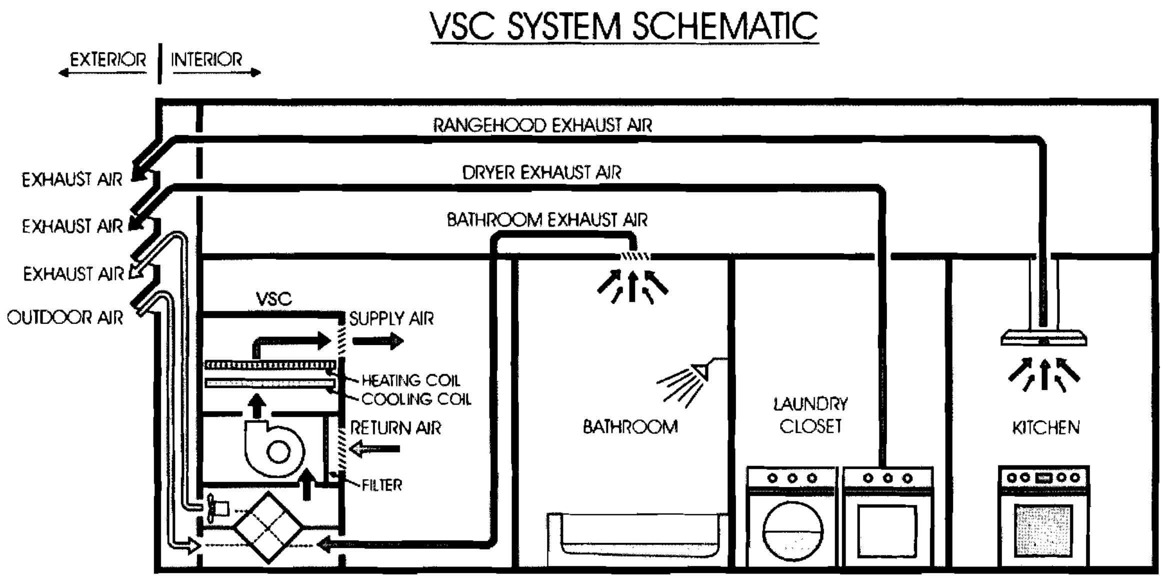

Figure 3 Suite ventilation schematic incorporating VSC.

3.6. Test Objectives and Methodology

All tests were performed on VSC units on the 5th, 8th, and 11th floors. Indoor and outdoor temperature, wind speed, and the indoor to outdoor pressure differences were measured to characterize the environmental conditions at the time of the test.

Tests included:

- VSC Air flow Capacity – This test was carried out to measure the ventilation, exhaust, and room air circulation flowing through the VSC under a variety of operating conditions. Exhaust airflows from the range hood and clothes dryer were also measured
- VSC Stall Test – This test was carried out to determine the relationship between the pressurization of a suite and the ventilation airflow rate through the VSC. This test provided some insight regarding the ability of that the VSC unit has to draw in outdoor air when operating against stack and potential wind pressures. The test was done with no other exhaust fans running, which is the case most hours of the day. The test was conducted by using a blower door to pressurize the suite relative to outdoors. The ventilation flow was measured at increasing increments of air pressure within the suite until a reversal in flow direction was observed.
- Air Leakage Characterization. This test was carried out to quantify the air leakage characteristics of the suites. A door fan was mounted in the corridor door and all

intentional openings (i.e.: range hood exhaust, clothes dryer exhaust, and bathroom exhaust) were sealed.

- Characterizing Air Pressure Regimes. This test was carried out to characterize the effects of operating the various exhaust fans in the suite on the air pressure within the suite and the impact of this on adjacent suites. Depressurization in the test suite was measured relative to outdoors as well as relative to the two adjacent suites on the same floor. A depressurization test was also carried out to assess combustion appliance spillage potential.
- Characterizing Corridor Air Leakage. This test was carried out to characterize the air leakage area of an entire corridor and the percentage of that leakage area attributable to the cracks around the doors to the suites.
- VSC Energy Consumption. Measurements were taken of the electricity consumption of the VSC and the corridor ventilation fan to determine the potential for energy use reductions through in the provision of in-suite ventilation as compared to central ventilation.

4. TEST FINDINGS

4.1. Ventilation Capacity - Code Considerations

The Ontario Building Code (OBC) requires mechanical ventilation at rates prescribed by ASHRAE Standard 62 "Ventilation for Acceptable Indoor Air Quality" (7.5 L/s per person). In this case (a one bedroom suite for 2 people in a high-rise) a minimum of 30cfm (15 L/s) continuous ventilation supply is required plus an intermittent exhaust capacity of 100 cfm (50L/s) for the kitchen. The VSC system, as designed and operated, almost meets these code requirements. This level of ventilation is significantly better than the ventilation supplied by the pressurized corridor technique.

Considerations for the Canadian climate necessitated these additional observations. While the ventilation fresh air was balance with the exhaust fan on low or medium, there was an imbalance when the fresh air fan was on high, a situation which could result in a winter freeze up of the heat exchanger core in the winter. In suites with poor building envelope air sealing, positive pressurization could also cause moisture problems in the walls and around windows. With the bathroom exhaust on high the exhaust airflow is about double the ventilation fresh air supply flow through the heat exchanger core. With such an imbalanced flow, it is unlikely that the core will ever develop frosting. However, it should be noted that were non-sealed combustion fuel-fired equipment supplied in the suite, negative pressures caused by excessive exhaust could cause back drafting and spillage of combustion products in the apartment.

Ventilation capacity is also affected with the increase of airflow caused by the use of a range hood and/or clothes dryer. The additional exhaust fans increase the negative pressure within the suite thereby potentially reducing the bathroom exhaust flows, and increasing the supply airflow and infiltration. The effect on the ventilation supply airflow is small when the suite corridor door is unsealed but is very significant, rising between 60% and 100% depending on the speed of the circulation fan, when the suite door is sealed.

4.2. Heat Recovery Opportunities

Typically, a bathroom fan would be set at low flow continuously and operate at high for ½ hour, twice a day. The clothes dryer would operate for 1 hour three times a week, with the range hood being used on high for 1 hour 5times a week.

Under this scenario, the great majority of heat to be recovered is available in the lowest speed of operation of the unit. A system that provides heat recovery on about 30 cfm of ventilation air while the bath fan exhausts 50 cfm continuously means that approximately 50% of the fresh air entering the suite during typical operation will run through the heat exchanger, significantly meeting about 26% of the ventilation air heating requirements.

4.3. Stall Test Findings

In all the test cases, when the air pressure in the suite was increased beyond the stall point, the airflow reversed direction and air was actually exhausted out through the ventilation duct. Recognizing that the air pressure in a building may be either greater than or less than the air pressure outside (depending on indoor and outdoor air temperatures, wind speed and direction, building height, and operation of HVAC equipment) it was recommended that the VSC be modified to ensure that the ventilation air supplied to the suite always meets or exceeds code requirements. This could be accomplished through simple controls that would regulate the speed of a VSD operated circulation fan based on airflow through the ventilation orifice.

4.4. Air Leakage Characterization

In the test building, each suite has a calculated floor area of 57.05 m2 (614.08 ft2), total envelope area of 192.69 m2 (2074.10 ft2), and volume of 156.32 m3 (5520.39 ft3). With the blower door installed in the corridor door, the air leakage was determined to be 2.37 air changes per hour at 50 Pa (ACH50) for suite 502, 2.41 ACH50 for suite 802, and 2.55 ACH50 for suite 1102, for an average of 2.44 ACH50. Another way of expressing air leakage is the Equivalent Leakage Area (ELA), which is the sum of the crack areas at a 10 Pa pressure difference. The average ELA for each of the three suites was 0.0135 m2 (21 in2).

In order to qualify the air leakage of the suites, we referred to the requirements of the R-2000 program. The R-2000 program is one of the highest technical standards in the world for new housing that ensures homes have a higher quality of construction, and are more energy efficient with better indoor air quality.

One requirement of the R-2000 program is that the normalized leakage area (NLA) must be less than 1.0 in2/100 ft2 (0.7 cm2/m2). The NLA calculated for the three suites tested ranged from 0.99 in2/100 ft2 to 1.05 in2/100 ft2, which is very close to meeting the R-2000 requirements. This indicates that the building is very well sealed. This tightness of the building envelope in combination with the individual ventilation units would provide for measurably increased indoor air quality conditions as compared to the average high rise.

4.5. Characterizing Air Pressure Regimes

Depressurization tests were carried out in several suites. This was measured by sealing the corridor door in each suite in addition to closing the balcony door and windows. A series of sequences of turning the various exhaust fans on and off, on low and high speeds were carried out. These de-pressurization test of each of the units demonstrated that, with the corridor doors sealed, there was practically no pressure interaction between the suites.

Combustion spillage is the term used to describe the unwanted flow of combustion gases into a space (e.g., home) by vented combustion appliances, such as fireplaces, and natural gas fired stoves or dryers. It occurs when the air pressure within the space is low enough that the exhaust fan for the combustion appliance cannot create sufficient discharge pressure to overcome the negative air pressure in the space. As a result, the airflow is reversed; called "back drafting", and gases are drawn back through the exhaust duct and into the space.

Combustion spillage typically occurs when the air pressure within the space drops below –5 Pa (relative to the outside air pressure). The testing in suites carried out on both calm and windy days yielded air pressures within the suites that were below –5 Pa, with corridor door sealed and unsealed. As a result, concerns with the potential for back drafting resulted in the recommendation that combustion appliances (e.g., gas fired dryer, wood or gas fireplace, or gas fired oven/stove) not be used in the suites.

4.6. What Was Learned

The field-testing of the VSC has demonstrated the great potential that this technology has in improving ventilation and indoor air quality in high-rise residential buildings. Clearly there are important considerations to make when dealing with the unique pressurization conditions that occur in multi-story buildings. Yet the technology has demonstrated that it can work well with modifications.

The next stage of product development and testing will incorporate all of the components of the single-family residential units developed under the eKOCOMFORT label. This will bring the individual heating unit into the high-rise building and provide another level of integration and other possibilities in the adaptation of spaces in high-rise buildings.

5. CHALLENGES FOR 'OPEN BUILDINGS'

The open building concept provides a number of new challenges for designers and builders. In addition to adapting structures to allow for future changes in use of buildings, the mechanical systems now used in high-rise buildings provide their own limitations and challenges. With eKOCOMFORT, the potential for providing heat, hot water and good ventilation, with a system that is compact and adaptable will soon be available.

New issues continually add to these challenges. For example, the recent SARS epidemic has raised fundamental questions regarding the potential for isolating individual units in high-rise dwellings to prevent the spread of potentially contagious infections. In the ever-increasing density of our urban populations, this issue may have a considerable impact on the future design of multi unit residential buildings.

In response to the SARS outbreak in Toronto, CMHC researchers examined the challenges of containment, initially developing the following recommendations based on the group's knowledge of air movement and ventilation in high-rise buildings:

For quarantined units:

- Seal the corridor door
- Contact with the corridor needs to be strictly prohibited.
- Increase the pressurization of the corridor to prevent air being drawn into the corridor from the quarantined unit
- Depressurize the quarantined unit through a combination of continuously running the bathroom and exhaust fans, and providing additional ventilation into the unit. Additional ventilation can be provided passively through the use of windows and doors, or actively by using a fan to increase the flow of air from the window and/or door opening into the quarantined unit.

For non-quarantined units

- Install fans to pressurize the units by bringing in additional air.

For the building

- Replace and maintain the seals on all entrance doorways into the building.
- Turn off the 24-hour time clock used for the ventilation of the building in order to maintain constant air pressure in the corridors.

When faced with our own questions as to how well these would work, we had no definitive answers. Should this situation happen during the winter months when windows remain closed, the potential for managing the situation seemed far more tentative. Clearly these are seen as band-aid solutions to the larger issue of the need for improved ventilation for high-rise buildings. Our work continues.

REFERENCES:

Canada Mortgage and Housing Corporation, 2003, *Field Testing of an Integrated Ventilation-Space Conditioning System for Apartments. Draft Report*, CMHC, Ottawa

Canada Mortgage and Housing Corporation, 2001, *Healthy High-Rise: A Guide to Innovation in the Design and Construction of High-Rise Residential Buildings*, CMHC. Ottawa

Canada Mortgage and Housing Corporation, *The eKOCOMFORT Field Assessment Program: Project Initiation Report*, 2003, CMHC, Ottawa

Buildings Group, Natural Resources Canada, 2002, *ēKOCOMFORT™ Field Monitoring Plan Final Report,* NRCan Ottawa