FIELD INVESTIGATION OF INDOOR ENVIRONMENT AND ENERGY USAGE OF MID-RISE RESIDENTIAL BUILDINGS

Introduction

In recent years, significant research efforts have been directed toward improvement in housing affordibility, durability, and sustainablilty. Canada's overall committment to reduction of greenhouse gas emisions will lead to more research to in energy saving housing technology. However, to date most research has been focused on the single detached housing which represents 70% of our housing stock. Consequently, less is known about multi-unit buildings. In 1990 CMHC initiated a number of studies to characterize energy consumption and indoor air quality in high-rise residential buildings, and more recently, to evaluate mid-rise buildings (3.5 to 5 storeys), two distinct forms which together represent the other 30%. This is a summary of results of the mid-rise investigation.

Description of Publication

The consultants set out to answer these questions about recently built mid-rise buildings:

- What is the airtightness of buildings built under the 1990 NBC air-barrier requirements?
- Do installed ventilation systems perform adequately?
- Are occupants satisfied with indoor conditions?
- What is the energy consumption of mid-rise buildings?
- How do these buildings compare with high-rise and single family detached housing?

The report summarizes the results of a series of field measurements of air leakage, ventilation system performance, energy consumption, actual ventilation rates, indoor air quality (both as measured and as perceived by occupants), and levels of electromagnetic fields in recently constructed mid-rise residential buildings. Appendices to the report detail the results for each building.

Eight buildings were investigated, 4 in Vancouver and 3 to 4 each in Ottawa and Toronto, all built between 1990 and 1995. They each had 3 to 4 storyes, and 17 to 45 suites. As it happens, all were built to accommodate seniors.

Research Program

Air Leakage

The building shell airtightness varied from 2.23 to 3.60 L/s•m^2 at 75 Pa pressure difference. Wall corners, roof/wall junctures, window-to-wall joints, balcony door frame-to-wall joints, basement/ground floor connections, and weather-stripping of windows and doors seemed to be the main causes of this leakiness.

These rates are similar to rates observed in high-rise buildings, and greater than rates observed in single family houses. They all greatly exceed NBC '95 recommended, and R-2000 required rates.

Envelope Air Leakage, L/s•m^2 @ 75 Pa

NBC '95 Recommendations	0.01 - 0.15
R-2000 requirement (ELA = 0.7 cm^2/m^2)	~ 0.64
High-rise field measurements building averages	~ 2.6 - 3.8
Mid-rise field measurements building averages	2.23 - 3.6
Tract housing field measurements	~ 1.4

Ventilation

Rate of air change in suites, measured over a week by passive adsorption of tracer gas, was from 0.1 to 2.04 AC/h. Estimated mechanical ventilation rates (excluding air leakage) were from 0.09 to 0.67 AC/h. Under the 1995 National Building Code, single family detached housing is required either to meet CSA F-326, which requires a rate of 0.30 AC/h, or to follow prescriptive requirements designed to provide the equivalent. Although this requirement does not apply to multi-unit buildings, it is reasonable that it should, particularly since air quality problems created by occupants are shared by their neighbors.

Seven of the eight buildings had corridor make-up air systems. The system design air flow rates met the requirements of ASHRAE 62-1989, but actual performance was another matter. Measured rates of flow to the corridors varied from 55 to 99% of design capacity for the building as a whole, and from 42 to 155% of design capacity for individual floors. More significantly, in four of the seven buildings, flow from corridors to suites was negligible because conflicting requirements for fire safety, acoustic privacy, and ventilation had been resolved by tightly weather-stripping and sealing the doors, the intended access to suites for make-up air. In the three buildings where rates were appreciable, air movement from corridor to suite varied from 13 to 27 L/s, or 43 to 108% of the CSA F326 rate. For these three buildings, the average rate was 63% of the required rate. For the other four buildings with corridor make-up air systems, flows to suites ranged from 0 to 13 L/s; the average rates were 3, 29, 13, and 5%, respectively, of minimum required. All suites had kitchen and bath exhaust fans with rated capacities meeting CSA F326 requirements, however measured flow rates were 30 to 85% of rated capacity for bathrooms, and 50 to 90% of rated capacity for kitchens. Surveys of occupants indicated that 82% of occupants regularly used kitchen fans, while only 41% regularly used bathroom fans. Although this conjecture was not tested, exhaust fans probably draw air from the exterior as much as from the make-up system, since make-up air is not finding it's way into the suites in most cases.

The under-performance of ventilation systems seemed to be associated with high levels of relative humidity, high levels of CO_2, window condensation, and mould growth in several buildings.

Immigrant families also live in dwellings in relatively good condition, compared to Canadian families in general. In 1991, 6.2 % stated they occupied dwellings needing major repairs, compared to 8.6 % and 11.6 % of young-couple and lone-parent families in general. Although renters comprise only 25.5 % of immigrant families, they constitute 36.8 % of immigrant families living in dwellings in need of major repairs.

Indoor Environment

Indoor environments of suites were assessed by measuring air temperature, humidity, CO_2, CO, Formaldehyde, selected VOCs, and EMF. Respirable particulates were not included. Measurements were made in three suites in each building. Temperature, humidity, CO_2, and CO were measured for 7 to 10 days and logged at 10 min. intervals. Formaldehyde was measured with dosimeters in each suite for 7 days. Individual VOC concentrations and TVOC were determined from sample badges exposed for 7 days. Electro-magnetic fields were measured in most of the sample suites, in living rooms, bedrooms, and bathrooms.

Temperature & Humidity

Mean temperatures in individual suites fell within the ASHRAE 52 recommended range of 20 to 24°C in 16 of 20 test suites. Mean RH fell within the ASHRAE recommended range of 30 to 50% in a different 16 test suites. In only one test suite was temperature always within the recommended range. In two test suites temperature was always above the recommended range. Individual RH values fell below the recommended range in 17 test suites, and were never higher than recommended.

Carbon dioxide and monoxide

All CO_2 measurements were lower than Health Canada guidelines of 3,500 ppm, and mean levels fell below ASHRAE recommended maximum level for occupant comfort of 1000 ppm in all but 4 test suites. The 1000 ppm level was never exceeded in 11 suites, and only 3 suites had levels exceeding 2000 ppm. The maximum recorded CO level was 7 ppm. In 16 suites the maximum level was about 1 ppm, compared with Health Canada's 8 hour exposure maximum of 11 ppm.

Formaldehyde

Formaldehyde concentrations, averaged over a week, ranged from 0.01 to 0.06 ppm. Health Canada recommends a maximum level of 0.1 ppm, and recommends remedial action be taken if levels exceed 0.05 ppm. In three suites this "action" level was met, and in one suite it was exceeded.

VOC and TVOC levels were below most currently recommended limits in all buildings. Maximum TVOC was less than 1.0 mg/m^3 in all cases and less than 0.5 mg/m^2 in all but one case. Sampling was done in bedrooms, not closets, kitchens, or bathrooms, so higher levels may exist in some cases. Recent research has indicated that levels of 0.2 to 3.0 mg/m^3 can cause discomfort.

Electromagnetic Fields

EMF levels were below the lowest of currently proposed maximum levels (3.0 milligauss), with few exceptions. The highest level measured was 8.45 milligauss, near an operating TV set.

Energy Consumption

Energy consumption of each building was simulated using DOE-2.1E, and reconciled where possible with billing data. In addition to temperature and lighting measurements, inputs were taken from building drawings, supplemented by site verification and measurements. Total energy consumption per unit of floor area was:

Total energy consumption kWh/m^2

Ottawa		Toronto		Vancouver			
150	263	170	219	152	175	146	199

As percentages of building energy budget during the heating season, estimated heat gains and losses were

Losses & Gains (% of building energy budget)

Losses	Mean,%	Range,%
Ventilation	16	7 - 21
Windows & Doors	30	18 - 38
Walls	16	5 - 29
Roof	6.5	4 - 11
Below Grade	7.5	1 - 17
Air Leakage	24	17 - 38
Gains		
Space Heating	70	62 - 81
Solar	10	7 - 13
Internal	20	10 - 28

Examination of as-built details indicated that adding insulation to walls, without changing details substantially to eliminate thermal bridges, would result in negligible improvement.

Occupant Satisfaction

An occupant survey, with responses from 20 to 94% of occupants, depending on building, resulted in the following ranges of opinion:

Occupant Satisfaction Survey Responses %

CONDITION	BC	Ontario
Temperature OK	50 - 93%	27 - 80%
too hot	3 - 29%	0 - 23%
too cold	0 - 4%	0 - 21%
inconsistent	0 - 43%	10 - 64%
Air Quality OK	44 - 97%	27 - 69%
stale	0 - 21%	0 - 16%
stuffy	15 - 36%	15 - 55%
drafty	3 - 7%	0 - 18%
Summer RH OK	50 - 90%	18 - 46%
too dry	10 - 21%	5 - 10%
too humid	0 - 24%	15 - 73%
Winter RH OK	54 - 73%	27 - 50%
too dry	12 - 29%	18 - 50%
too humid	3 - 12%	0 - 55%

Occupants reported the following problems:

Problems Reported	BC	Ontario
Window condensation	4 - 21%	8 - 91%
Mould	0 - 14%	0 - 45%
Disagreeable Odours	13 - 44%	31 - 91%
Health problems attributed to building	4 - 16%	9 - 31%

Implications for the Housing Industry

- Air leakage is a significant energy loss in current mid-rise buildings. It also exceeds limits recommended to prevent condensation and deterioration of the building envelope, potentially a more serious problem. Both design and construction practices need improvement to reduce air leakage. Reduction of air leakage will require compensating improvements in ventilation, to maintain or improve air quality.
- Air change rates in suites vary widely. In 25% the buildings, they were less than 10% of what is required for single detached dwellings. Corridor make-up air systems do not effectively transfer fresh air to suites. Instead of using suite doors to transfer fresh air from corridor to suite, some other means is required which does not create conflicts between ventilation requirements on one hand, and requirements for fire safety, smoke control, and acoustic privacy, all of which require sealed doors, on the other.
- Mid and high-rise buildings rival (and even surpass) single detached houses in energy consumption, compared by normallizing for climate and floor area. Yet, because of their lower surface to volume ratios, they should consume less, so there is ample opportunity for improvement.
- Significant numbers of mid-rise building occupants are dissatisfied with air quality. Still, measured concentrations of CO, Formaldehyde, and, VOCs (depending on emerging standards), often suspected causes of poor air quality, are all within accepted limits. CO_2 concentrations, on the other hand, often exceed 1000 ppm. High levels are found in suites with low air change rates. More effective ventilation with better distribution, not greater volume or energy consumption, might increase occupant satisfaction.
- EMF levels do not appear to be a problem.

Project Manager: Duncan Hill, P.Eng.

Research Report: Field Investigations of Indoor Environment and Energy Usage of Mid-Rise Residential Buildings, August 1997

Research Consultant: Scanada Consultants Limited

A full report on this project is available from the Canadian Housing Information Centre at the address below.

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