CMHC's Integrated Design Competition for High-Rise Residential Buildings

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1. Background to the Competition

High-rise and mid-rise apartment buildings currently provide housing to 17% of Canadians. This building type already fulfills a key role in providing affordable housing for the elderly, single parent families, smaller households and the disabled, and may constitute an increasing percentage of the future housing stock, particularly as a response to the need for increased urban density.

However, unlike low-rise wood-frame housing, which has benefitted from considerable R & D and undergone a significant evolution since the 1970s, high-rise residential construction has been slow to adopt improvements. Beyond the fine finishing materials in the lobby, the general quality of apartment construction can be quite low, leading to premature failure of building components. Such problems have become a major cause of concern to building managers and owners, condominium unit owners, warranty programs and mortgage insurers. Repair costs can be very high.

In Ontario, for example, studies suggest that more than half of the new condominium buildings constructed in recent years have developed serious problems during the initial years of occupancy (1). Building envelope problems are by far the most common. Comfort-related occupant complaints are also widespread, indicative of poor control over air distribution and air quality. In addition, high-rise buildings have been found to consume energy at a similar rate per floor area as low-rise detached dwellings, in spite of their superior surface-area-to-volume ratios.

The underlying reason for most of these problems is that the level of understanding of building science among designers and contractors has not risen in proportion to the increased performance requirements being placed upon buildings. Construction details are often missing or inaccurate. System interactions are not considered. Designs are not sufficiently "forgiving" and cannot accomodate imperfect construction practices. Inspections and quality control, at both the plans review stage and during construction, are inadequate. All of these weaknesses are exacerbated by highly competitive market conditions which place severe constraints on both design fees and construction costs.

2. Recent Research on Building Envelopes and Ventilation Systems

Canada Mortgage and Housing Corporation (CMHC), the federal government's housing agency and the major insurer of residential mortgages, has undertaken various research and technology transfer initiatives to improve the quality of high-rise residential construction. Much of this has been done in collaboration with other agencies, particularly the Ontario New Home Warranty Program, the National Research Council, Ontario Hydro, building envelope councils and architectural associations. Two areas of focus have been building envelopes and ventilation systems.

With respect to building envelopes, CMHC has sponsored research initiatives on materials, systems and detailing for air barriers; the implementation of rain screen principles in a variety of wall types; the actual airtightness characteristics of apartment units, entire floors and whole buildings; and the development of air leakage control retrofit strategies. The complex problem of masonry veneer failures on steel stud walls has been studied in detail, with various remedial and preventative solutions developed. More recently, exterior insulation and finish systems (EIFS) have been studied. Extensive seminars have been delivered to designers and contractors on air barriers and masonry veneer systems.

With respect to ventilation, CMHC has examined air movement patterns in high-rise apartment buildings, developed test protocols for indoor air quality, and conducted an extensive survey of current HVAC design practices and problems. Current work involves investigating venting problems associated with exhaust fans and combustion appliances due to high pressure differentials. Seminars have been conducted for architects on indoor air quality.

The results of this research work has led CMHC to the following key conclusions:

2.1 A high degree of airtightness is essential for the durability of the building envelope.

Air barrier and rainscreen technologies, while being increasingly promoted, remain poorly understood. Typical apartment buildings have air leakage rates of 0.7 to 11 L/s-m^2 of envelope area at an indoor/outdoor pressure differential of 50 Pa (2). The heat loss associated with this air leakage represents 32% of the heating cost and 36% of the peak electrical demand in typical electrically heated buildings (3). Worse, the flow of moisture-laden air through the envelope and the lack of control over rain penetration causes the deterioration of cladding and sheathing and the corrosion of metal anchors. It has been estimated that some 95% of all condominium warranty claims are related to water in one form or another.

2.2 An airtight envelope is also essential for the ventilation and heat distribution systems to be effective.

Few designers and contractors are fully aware of the close inter-relationship between the building envelope and the ventilation system. A common scenario often unfolds as follows. A 20 storey apartment building with a leaky envelope will develop very large pressure differentials of say, 130 Pa between the ground floor and top floor. High rates of infiltration on the ground floor will create uncomfortable conditions for occupants, who will then turn up their thermostats. Meanwhile, the upward flow of air through the building and the additional heating of the lower floors will lead to occupant complaints of overheating on the top floors. These occupants will then leave their windows open much of the time, even in cold weather. This further increases the stack effect in the building and the rate of lower floor infiltration, leading to thermostats being turned up even higher, windows being opened even wider, etc., etc. The net result is a building in which the ventilation and heat distribution system have been completely overpowered by stack action, occupants are uncomfortable, odour control is negated, and high energy costs are incurred for air leakage and unnecessary mechanical ventilation. In addition, serious air quality problems can be created from the excessive infiltration of pollutants from parking garages and garbage rooms into ground floor suites. A recent survey of HVAC design professional has indicated that the development of economical ventilation systems which can control infiltration and odours is a priority (4).

2.3 Durability needs to be considered as an essential aspect of the energy and environmental performance of buildings.

The significant amount of embodied energy associated with the construction of a large building can be equivalent to 8-10 years of operational energy. Some recent examples of particularly catastrophic cladding failures have resulted in literally millions of bricks being carted away to landfill sites. Prolonging the life of building envelopes and the structural and finishing components they protect can therefore greatly reduce the building's life cycle consumption of energy and resources.

3. The Need for a Competition

Competitions and demonstrations are the most powerful form of technology transfer. As evidenced by CMHC's "Healthy Housing Design Competition" and EMR's "Advanced Houses Program", a national competition can generate tremendous interest within the design community and construction industry, and can lead to many practitioners "buying in" to new ideas. Demonstrations can provide the necessary performance data to convince skeptical designers and owners. However, unlike low-rise housing, which provides many low-cost opportunities for demonstrations, large buildings are expensive, risky and complex to develop, and therefore the number of state-of-the-art examples are very few.

Therefore, to stimulate improved high-rise design and construction practices, CMHC is sponsoring a national design competition and demonstration program in 1993-94, the "Integrated Design Competition for High-Rise Residential Buildings". The competition objective is to develop and demonstrate integrated solutions to durable building envelopes and effective ventilation systems, while at the same time improving energy and environmental performance, and remaining economically and functionally viable.

CMHC's competition complements the development of the Advanced Commercial Buildings Program - C2000 - which is being sponsored by Energy Mines and Resources/CANMET with funding under Canada's Green Plan. EMR is currently developing detailed criteria for high-rise residential and office buildings, encompassing a comprehensive set of energy, environment, indoor environment and functional performance characteristics (5). CMHC's competition seeks to support the C2000 Program by developing and demonstrating significant break-throughs in two areas which are crucial to the performance of advanced buildings - the envelope and the ventilation system.

4. <u>Competition Technical Criteria</u>

The technical criteria for the competition have been grouped under five categories: durable building envelope, effective ventilation system, integration of envelope and ventilation design, improved energy and environmental performance, and economic and functional viability. Of these, the first three have been given the greatest weighting within the competition.

4.1 Durable Building Envelope

For the purposes of the competition, the building envelope includes below grade walls, exterior walls, windows, roofs and soffits, but the main focus will be on exterior walls, where the problems are numerous and complex. The overriding competition requirement for a durable building envelope is to be as maintenance-free as possible for 35 years. Characteristics to be considered include the following:

- Airtightness: Envelope air leakage should come as close as possible to meeting the proposed guidelines of 0.05-0.15 L/s-m^2 @ 75 Pa determined by the National Research Council as optimum in avoiding moisture problems. Existing high-rise buildings typically have air leakage rates 20 to 50 times this level, and even a detached house meeting the R-2000 airtightness requirements is approximately 7 times as leaky. There is as yet insufficient data on the airtightness of new buildings constructed with continuous air barriers to judge how achievable are the NRC guidelines. Ensuring the continuity of the air barrier across joints in materials and at the juncture of major assemblies is essential. The components making up the air barrier should be durable, structurally supported and easily accessible.

- Compartmentalized rainscreen: To prevent rain penetration, it is necessary to neutralize pressure drops across the cladding. The performance of a rainscreen is, of course, highly dependent on the previous requirement for airtightness. Baffles are required to prevent air flow within pressure-equalized cavities. Corner conditions are particularly crucial because of the dramatic changes from pressurization to depressurization. Any moisture which does find its way into the wall needs to have a drainage path to the exterior.

- Minimal reliance on short-lived components, such as sealants, for good air barrier and rainscreen performance.

- Robust components: Materials must be resistant to local damage, such as from wind gusting, ultraviolet degradation and vandalism.

- Moisture-resistant foundation walls: The entry of ground water and surface run-off into basement suites and parking garages is to be prevented.

- Adequate commissioning: To verify airtightness and rainscreen performance, commissioning procedures need to be developed for specific wall assemblies for implementation both during construction and upon completion of the building.

4.2 Effective Ventilation System

The building's ventilation system must be capable of creating a healthy indoor environment with good indoor air quality in each suite and in common areas, while maintaining comfortable conditions for the occupants. At present, there are few standards or guidelines which comprehensively address the unique challenges associated with providing ventilation in high-rise residential buildings. The minimum competition requirement is to meet the appropriate criteria specified in CSA Standard F326.1 "Residential Mechanical Ventilation Requirements", which is intended for low-rise construction, and ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality". Key characteristics to be considered include the following:

- Balanced system: There should be no reliance upon envelope air leakage and minimal reliance on corridor leakage for the supply of fresh air to suites.

- Variable air change rates: Ideally a minimum level of continuous ventilation (or perhaps two minimum levels for occupied and unoccupied conditions) should be provided, plus the capacity for considerably higher levels as required by occupant activities.

- High performance exhaust systems: Performance must be maintained under a wide range of pressure differentials. Fans must be capable of overcoming negative pressure differentials on lower floors; dampers must remain closed against positive pressure differentials on upper floors.

- Distribution of fresh air to all bedrooms, and preferably all habitable rooms.

- Maintaining carbon dioxide levels below 1000 ppm: This is the guideline level specified by ASHRAE as a surrogate for human comfort and odour control.

- User-friendly controls: A combination of automatic controls governed by RH and/or CO_2, and direct occupant controls over air change rates and humidity levels should be provided.

- Pollutant source control: Measures should be taken to prevent the ventilation system from becoming a source of biological or chemical pollutants. Inlets should not draw contaminants from parking garages or combustion appliances into the building; ducts, filters and humidification/dehumidification equipment should not promote mould growth; odours should not be drawn from other suites.

- Occupant comfort: Drafts and excessive temperature swings should be prevented; fresh air should be tempered; fans should be rated at 2.0 sones or less.

- Smoke control: Innovative ventilation systems must not compromise fire safety requirements. The movement of smoke into suites and fire exits must be restricted.

- Adequate commissioning procedures to verify flow rates, air change rates and functioning of controls.

4.3 Integration of Envelope and Ventilation Design

CMHC's competition stresses the need to integrate the design of the building envelope and the ventilation system. System inter-relationships must be considered, with full advantage taken of beneficial system imteractions and steps taken to minimize any negative interactions. In particular, competitors must address the following two key challenges:

- Strategy for reducing stack pressure differentials: If the stack effect can be reduced, it will be much easier to provide effective ventilation and thermal comfort, since the pressure differentials between the suite and the exterior will be in the order of a few Pa, rather than tens or hundreds of Pa. Reducing the stack effect requires that floors and/or suites be aerodynamically "de-coupled". Studies have shown that there is already a reasonable degree of airtightness between floors, suites and corridors, without any particular attention being paid to air sealing. Only 5-15% of a typical suite's air leakage is through the corridor wall and entry door, 10-30% through interior walls, 5-15% through floors and 5% through ceilings, in comparison with 40-60% through exterior walls (6). Greater attention to air sealing measures would isolate each floor or suite more successfully. More importantly, vertical shafts need to be isolated from the building floors. Air leakage into an elevator shaft or a stairwell can equal or exceed the exterior wall air leakage for an entire floor (2). Elevators may require vestibules; stairwells and garbage chutes may require more airtight doors; bathroom exhaust systems and corridor supply systems may need to be eliminated and replaced with separate systems on each floor (7).

- Strategy for dealing with operable windows: Unlike office buildings which generally have windows which cannot be opened, residential buildings have operable windows and balcony doors controlled by occupants. Such openings obviously overwhelm any attempts to make the envelope airtight and wreck havoc with mechanical ventilation patterns. The competition seeks innovative solutions to this dilemma. Addressing the first challenge above - reducing stack pressure differentials - will clearly make the second challenge more manageable.

4.4 Improved Energy and Environmental Performance

Energy losses associated with air movement, in the form of envelope air leakage and unnecessary mechanical ventilation, make up a significant share of the space heating losses in typical high-rise residential buildings, usually in the range of one third. A more airtight envelope and a more effective ventilation system therefore achieve substantial energy savings. Also, improved envelope durability leads to reduced life cycle use of resources and energy. In addition to documenting these savings, competitors will be encouraged to respond to the full range of energy and environmental criteria being developed for the C-2000 Program.

- Improved thermal resistance: Designs should provide thermal performance levels for walls, roofs and windows which significantly exceed the requirements of ASHRAE Standard 90.1-1989, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings". Specific requirements are currently being developed in coordination with the C-2000 Program. ASHRAE 90.1 deals particularly harshly with the presence of thermal bridging, and therefore the competition will encourage innovative solutions for two common problems: balconies and masonry veneer supported on shelf angles.

- Minimal fan energy: Attention has recently been focussed on the poor energy efficiency of fan-motor sets. To encourage the development and adoption of more efficient equipment, the competition limits power demand for fan systems at design conditions to 1.6 W/L-s of supply air for constant volume systems and 1.9 W/L-s of supply air for variable air volume systems.

- Heat recovery: Opportunities for recovering heat from exhaust air are to be incorporated into the ventilation system.

- Environmental responsibility: Designs should specify no use of chlorofluorocarbons in materials and equipment, lead to minimal use of non-renewable resources, incorporate recycled materials where feasible, and facilitate minimal on-site generation of pollutants and construction waste.

4.5 Economic and Functional Viability

In order for improved design and construction practices to be widely adopted throughout the industry, they must be perceived to be practical and economic. These "real-world" constraints create the following additional requirements for the competition:

- Reasonable incremental costs: The additional costs of advanced technologies over conventional design and construction should not pose a major deterrent to building owners, and should be readily offset by payback opportunities arising from long-term savings in maintenance, replacement and energy usage.

- Functional design: Envelope and ventilation system innovations should be part of an overall building design which is efficient, functional and aesthetically attractive, in order to be marketable to owners and occupants. Designs should take into consideration local site conditions and the impact on neighbouring buildings. Of particular interest to CMHC is the issue of barrier-free accessibility, which should be incorporated wherever possible.

- Buildable: Improved practices should be adaptable to current trade deployment and scheduling. Details should be practical to assemble on real construction sites under adverse weather conditions.

- Opportunities for Canadian technology: Canada is already recognized as a world leader in low-rise wood-frame construction for cold climates. Solutions emerging from this competition should contribute to business and export opportunities for Canadian industry.

The following outlines the weighting factors to be applied with these criteria:

Durable Building Envelope	30%
Effective Ventilation System	20
Integration of Envelope and Ventilation Design	20
Improved Energy and Environmental Performance	15
Economic and Functional Viability	15

In addition to the above technical criteria, designs must meet the intent of the provincial building code requirements and municipal codes and bylaws applicable to the proposed building location.

5. Competition Structure and Evaluation Methods

A two stage "ideas" competition with a follow-up demonstration phase has been chosen as the optimum approach to ensure the involvement of the greatest number of design professionals and the realization of viable demonstration projects.

The competition has no fixed design categories, but does encourage a range of solutions to address low-cost rental apartments, higher cost condominiums and regionally appropriate designs. Buildings which are already at the design or construction stage may also be eligible, providing that design changes can still be made to allow the building to meet the competition's technical criteria.

The evaluation process will be undertaken by a jury of building envelope and ventilation experts, and will combine both quantitative and qualitative methods.

5.1 1st Stage

The 1st Stage of the competition will be open to a broad cross-section of the design community and construction industry. The formation of multi-disciplinary teams will be encouraged, consisting of provincially registered architects and mechanical engineers, building science and envelope specialists, and potential building owners or developers. In response to the technical criteria and background information outlined in the Competition Guide, competitors will submit a brief description of their design concept, supported by schematic drawings, plus information on their team members and on opportunities for a demonstration phase.

Judging of the 1st Stage submissions will be largely qualitative, with the jury assessing the potential merits and innovativeness of the concept proposed, the strength of the team, and the feasibility of a future demonstration project, while also attempting to acheive a regional distribution of finalists and a mix of building types and sizes. Five finalists will be selected to proceed to the 2nd Stage, and will receive funding from CMHC to assist in the development of their submissions.

5.2 2nd Stage

In the 2nd Stage of the competition, finalists will submit detailed designs for the building envelope and the ventilation system, descriptions of the strategies proposed and the underlying rationale, computer simulations and various calculations. A firm proposal for the demonstration phase will also be required, and will include time schedules, commissioning procedures and arrangements for additional funding.

At the 2nd Stage, a more quantitative technical evaluation will be possible, including estimated airtightness, rainscreen performance simulation results using the RAIN software, calculated thermal performance of the envelope and ventilation system, estimated reduction of stack pressures, design data on air change rates and supply and exhaust capacities, predicted CO_2 levels, calculated heat recovery potential, and estimated incremental costs. A qualitative assessment will still be required in judging the "buildability" of construction details, the expected durability and maintenance characteristics, the feasibility of control strategies, any anticipated comfort and performance problems, the expected system interactions, the rationale underlying the design, and the adequacy of proposed commissioning procedures. The feasibility of the submissions for real-world demonstrations will also need to be assessed and will involve both a quantitative check on time frames, incremental budgets and leveraged funding, and a qualitative evaluation of the team's project management strengths, experience and flexibility.

5.3 Demonstration Phase

Negotiations will be undertaken with the competition winner(s) regarding the demonstration phase. Additional CMHC funding will be provided to assist with incremental design costs, incremental construction costs, monitoring and documentation. The number of demonstrations to be built will depend on the quality of the submissions and on the amount of funding available - both from CMHC and from other sources. Ongoing evaluation during the demonstration phase will involve the laboratory testing of mock-ups, on-site commissioning and long-term monitoring, with periodic refinement of the design and construction to ensure that a high level of performance is achieved.

6. Timing, Implementation and Marketing

The competition's critical path begins with the completion of parallel activities now underway in preparing the Competition Guide, developing promotional materials and selecting the jury. This will be followed by promotion of the competition and distribution of the competition documents this summer. Approximately 3 months will be available for each stage, with the 1st Stage closing in early fall and the 2nd Stage closing in mid-winter. Negotiations with the winner(s) are expected to lead to the initiation of demonstration(s) during 1994.

It is recognized that the current economic situation represents a challenge to the success of the competition, since there are considerably fewer construction starts than were typical in the late 1980s, and since design and construction budgets are very tight. Marketing of the competition will therefore emphasize the competitive advantages of higher performance designs and the long-term cost reductions associated with more durable and complaint-free buildings.

Marketing vehicles will include direct mailings of brochures to architects, mechanical engineers, developers, contractors, major housing owners and housing agencies; the placement of ads and announcements in trade and professional journals; and the promotion of the Competition Guide as a valuable reference document on high-rise residential design and construction.

7. Conclusions

CMHC believes that an integrated approach to durable building envelopes and effective ventilation systems is essential to the performance of advanced high-rise residential buildings. The national design competition and demonstration program being sponsored in 1993-94 will allow the design professions and the construction industry to apply the results of recent research to develop solutions to some of the current technical challenges. The competition and subsequent demonstration phase are expected to promote improved design and construction practices, lead to superior long-term energy and environmental performance, and lend support to the C2000 Program being developed by Energy Mines and Resources/CANMET.

8. References

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