Healthy Indoor Environments for Energy-Efficient Housing

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ABSTRACT

This paper is a synthesis of research undertaken by Canada Mortgage and Housing Corporation (CMHC) on two residential indoor air quality issues: (a) integrating healthy indoor environments with concerns over the global environment and (b) designing for the chemically hypersensitive. Results suggest that for the general population, building envelopes and mechanical systems can be designed and built to maximize energy performance while minimizing the contribution of combustion gases, molds, soil gases, and material emissions to the indoor air, thereby resulting in housing that is "healthy" for both the occupants and the global environment. For the environmentally hypersensitive, the creation of healthy, yet affordable, housing remains a challenge due to the current degree of customization required.

INTRODUCTION

Although most research on the indoor environment has focused on commercial and institutional buildings, residential indoor air quality (IAQ) is also very important due to the large amount of time spent indoors, particularly by those segments of the population whose health is fragile and who may be more susceptible to low levels of pollutants, such as infants, the elderly, pregnant women, and those who are ill.

Canada Mortgage and Housing Corporation (CMHC) became involved in residential IAQ research in the early 1980s due to concern over carbon monoxide poisonings, moisture problems, and the provision of suitable shelter for the chemically hypersensitive. In many cases, these problems were perceived to be associated with changes made to houses to achieve energy efficiency. From these beginnings, CMHC has pursued a "systems" approach to integrating IAQ and energy efficiency, which has included surveys, laboratory and field tests, computer modeling, standards development, and information transfer. CMHC's research has focused on two objectives: (a) for the general population, the integration of improved indoor environments with global environmental concerns, and (b) for the chemically hypersensitive, the creation of specialized housing.

This paper represents a synthesis of the results and observations arising from this research. Details are provided in the reports listed as references.

HEALTHY HOUSING FOR THE GENERAL POPULATION

In response to growing concern over the state of the global environment, CMHC has undertaken a serious examination of how cold-climate housing could be built and operated more in keeping with the principles of sustainable development. Although the range of current environmental issues is broad, many revolve around energy use, including issues such as global warming, depletion of the ozone layer, acid rain, flooding of aboriginal lands, disposal of radioactive waste, and deforestation. Therefore, energy consumption can often be used as a practical surrogate for many environmental issues, and this is leading to a rekindled interest in energy efficiency.

Past energy conservation practices have often been a major factor in causing poor indoor air quality. A common example has been airtightening without providing adequate ventilation, which can result in elevated levels of pollutants and relative humidity and in some cases can cause heating appliances to spill combustion products. Moisture-related mold problems may prove to be the most significant IAQ hazard, with recent studies (Dales et al. 1990) linking housing dampness with respiratory disease.

However, the results of CMHC's building science research during the past decade suggest that the goals of energy efficiency and indoor air quality are not necessarily contradictory. Measures to increase energy efficiency can improve rather than worsen the quality of the indoor environment, depending on the manner in which they are undertaken. Similarly, indoor air quality measures can be undertaken in a manner that improves energy efficiency.

Energy-Efficiency Measures That Can Benefit the Indoor Environment

Increased Thermal Insulation Increased levels of thermal insulation in the building envelope create warmer surfaces, thereby eliminating or reducing the amount of surface condensation and related mold growth. However, local condensation can still occur unless construction details are employed that prevent thermal bridging, such as eliminating unnecessary framing lumber at corners and intersections or using exterior insulating sheathings. Also, higher insulation levels alone cannot prevent, and in some cases may actually increase, the occurrence of interstitial condensation unless proper attention is paid to the location of the insulation and air and vapor barriers. Since envelope cavities on the exterior of the insulation will be colder, the drying potential of attics and walls is reduced; therefore, it is more important to eliminate the migration of water vapor to these cavities. The common practice of placing insulation on the interior of the foundation has been found to virtually guarantee basement wall condensation problems in new housing in the spring and summer, due to the compounding factors of soil thermal lag and saturated concrete and the great difficulty in

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ensuring a continuous air or vapor barrier (MacInnes 1987). Exterior insulation systems are being strongly recommended (Becker and Platts 1989).

Control of Air Movement through Envelopes Increased airtightness of the inner surface of the building envelope can reduce the infiltration of pollutants from building materials within the envelope, such as fibers and volatile organic compounds from insulation. Increased airtightness of the subgrade envelope can similarly reduce the entry of soil gases, such as radon and methane, molds, and water vapor. However, airtightening without providing adequate mechanical ventilation can lower overall air change rates to the point where interior humidity and pollutant levels rise. As recent studies (Haysom et al. 1990) have shown, the airtightness of typical new Canadian homes has increased by 30% in recent years, such that the air leakage, averaged over the heating season, fails to meet air change requirements in 70% of housing, while a greater number fail on a monthly or daily basis—90% and 99%, respectively. Controlled mechanical ventilation systems are, therefore, required to reduce interior pollutant concentrations.

An alternative to airtight envelopes is to control the inward flow of air by creating a deliberate pressure differential across the envelope. Although this "dynamic wall" strategy has been shown to reduce total energy consumption by 14% in a typical two-story home (Timusk et al. 1987), critics have noted the potential for increasing the infiltration of pollutants both above and below grade. A promising "systems approach" solution, which needs to be field tested, is a controlled depressurized cavity within the envelope, preferably on the warm side. This depressurized cavity (either an airspace or a space insulated with drainage-type insulation) within the wall can be linked to centralized heat recovery, while pollutants can be safely excluded from the interior. By locating the insulation on the exterior of the structure, a continuous thermal break is also ensured, and the structure benefits from a stable thermal and moisture environment (Russell and White 1990). An analogous approach is already being used successfully in subslab ventilation for radon control and in cavity systems for below-grade walls and floors (Walkinshaw 1990).

Improved Window Performance The advent of "superwindows" with improved thermal performance reduces or eliminates a major source of condensation and related mold growth. By reducing uncontrolled convective currents and air leakage, such windows may also make certain ventilation strategies, such as displacement ventilation, more practical.

Increased Efficiency of Heating Appliances The venting of combustion gases from naturally aspirated appliances has depended on the vagaries of weather, indoor/outdoor temperature and pressure differentials, and educated homeowners. Surveys have found significant spillage of combustion pollutants in approximately 10% of gas furnaces and 28% of oil furnaces (Haysom et al. 1987). Higher-efficiency heating appliances provide improved venting of combustion gases through draft-inducing fans.

However, inappropriate installations can still have combustion spillage via leaky flues and fans. Studies have found that typical mid-efficiency gas furnaces spill 15% of their combustion gases at 20 Pa (0.08 in. H_2O) of depressurization, causing CO_2 levels in the home to exceed the Canadian health guideline of 3,500 ppm (Moffat 1991). It is, therefore, recommended that greater quality control be required in system installation or that draft-inducing fans be located outside the building envelope. Also, the lower rates of air change associated with higher-efficiency heating systems can have the same effect as airtightening in causing higher interior pollutant concentrations.

Increased efficiencies of air- and ground-source heat pumps, combined with the general downsizing of heating and cooling capacity due to envelope improvements, have created the opportunity for low-temperature heat sources, thereby avoiding the production of volatile organic compounds from the "frying" of synthetic particulates on heat exchangers or electrical coils.

Indoor Air Quality Measures That Can Benefit Energy Efficiency

Controlled Ventilation Controlled mechanical ventilation systems work in partnership with more airtight envelopes and offer the possibilities of centralized heat recovery from exhaust air. Even without heat recovery, controlled ventilation offers energy savings over uncontrolled air leakage. For air leakage to be sufficient to provide an average air change rate during the heating season that is equal to current Canadian code requirements of 0.3 air changes per hour ventilation capacity, a building would have excessive air change in the coldest period, when the energy penalty is high, while having insufficient air change during the shoulder seasons. The net result, as calculated for milder Canadian locations, is an increase in ventilation energy of approximately 25% (White 1991a). Demand-controlled ventilation systems, which alter the rate of ventilation to match ventilation needs, have been shown to have the potential to reduce the energy penalty associated with mechanical ventilation in an energy-efficient home by 8 to 16 GJ (75 to 150 therm) per year, an amount similar to heat recovery ventilators, while at the same time providing improved air quality during periods of peak pollutant generation (Moffat et al. 1991). Controlled ventilation also provides the opportunity for centralized air-cleaning and for the previously mentioned subslab and cavity depressurization systems. Local ventilation can reduce pollutant sources, thereby lowering overall ventilation requirements.

However, increasing reliance on mechanical ventilation will entail significant energy penalties unless component performance can be improved. CMHC has determined that the efficiency of typical residential fan/motor sets is only 3%, with a range of 1% to 6% (White 1991b). Also, if not properly designed, installed, used, and maintained, ventilation systems can themselves be a major cause of indoor air quality problems. Air-conditioning units, filters, ductwork, humidifiers, and dehumidifiers can be sources of molds. Improperly balanced systems can increase the rate of soil gas entry and combustion spillage (depressurization) or increase the deposition of moisture in envelope cavities (pressurization).

Selection of "Low-Pollution" Materials Reduction of pollutant sources offers the possibility of reduced overall ventilation rates and related energy. Another possible energy advantage of low-pollution materials is their relationship to "embodied energy"—the energy consumed in the production and transportation of building materials. Recent research has determined that embodied energy can be as high as the life-cycle operating energy for an energy-efficient house in a cold climate (Moffat and Cooper 1991). An initial observation arising from this work is that many materials with low outgassing rates also have low embodied energy, particularly for those materials produced by the petrochemical industry. There are, of course, many exceptions.

Moisture Source Control The reduction of a dwelling's moisture generation rate—from external and ground sources, occupant activities, the drying of construction materials, and seasonal moisture storage—in addition to controlling mold and dust mites, has energy conservation advantages. The degradation of the thermal performance of insulation is avoided; the greater longevity of building components reduces life-cycle embodied energy; dehumidification requirements are reduced; and the latent heat requirements for moisture entering via soil gas are reduced. Also, the careful maintenance of HVAC appliances, such as humidifiers and air-conditioning units, to prevent mold growth may help to improve the efficiency of such appliances.

HEALTHY HOUSING FOR THE ENVIRONMENTALLY HYPERSENSITIVE

While hypersensitivity has been formally recognized in Canada as a disability, persons suffering from environmental illness still find great difficulty in obtaining suitable accommodations. In the early and mid-1980s, CMHC pioneered some of the earliest investigations on hypersensitivity in Canada, focusing on identifying residential indoor pollutant sources.

In 1986, CMHC adapted its Residential Rehabilitation Assistance Program (RRAP) to recognize environmental hypersensitivity as a disability that warranted financial assistance for home modifications. RRAP has provided approximately 70 grants per year of up to $5,000 to individuals or families with such sensitivities. The most common modifications have been changes to the heating, ventilating, and air-filtration systems. Changes to wall and floor coverings are also common.

Two studies were completed in 1990, one a compendium of examples of "clean air" housing built or retrofitted across Canada and the other a survey of the medical impact of a change in habitat.

From approximately 200 responses to ads and requests, 92 cases of hypersensitivity were selected for investigation (Drerup et al. 1990). The results from a lengthy questionnaire on respondent health and residence confirmed a wide variation in sensitivities, health symptoms, and physical solutions attempted. In new construction, the most common measures were electric heating or isolated combustion boilers (93%), ceramic or hardwood floors (85%), custom wood cabinets (63%), avoidance of plywood and composition boards (48%), ventilation systems with air filtration (44%), ventilation-only systems (33%), and plaster or solid wood interior finishes (22%). The most common measures in renovated dwellings were changes to heating system (71%), changes to flooring or floor coverings (67%), portable air cleaning (52%), changes to cabinets and furniture (46%), and installing a central ventilation system (17%).

Another major finding was the confirmation of higher costs due to customization and the time spent seeking special materials and equipment. The single most important aspect of housing for the hypersensitive is the need for a "sniff test" on all materials, especially those that have direct or even indirect exposure to indoor air. In addition, there is a need for an unusual level of cleanliness during construction, including the avoidance of gas, glue, and pesticide spills, an on-site no-smoking policy, no burial of construction debris, meticulous cleaning of the HVAC system, and removal of dust. Additional costs are also incurred because of more sophisticated ventilation and filtration systems and the use of less common skilled trades, such as plasterers and tile setters.

In a complementary study (Barron 1990), the medical histories of 29 persons from the sample were examined in more detail by a physician. While measurements were not available of pollutant levels before and after physical changes had been made, it was determined, on the basis of responses and interviews, that a systematic and significant removal of pollutant sources had improved the health and functioning of approximately 85% of such people to a very marked degree.

DISCUSSION

The energy crisis of the 1970s may eventually be regarded as a positive learning experience in that it encouraged the development of a much improved understanding of the relationships between energy efficiency and indoor air quality. There is now a need to share this improved understanding of system interactions with many actors—designers, manufacturers, builders, trades, code officials, owners, and occupants. Demonstrating that low-energy buildings can have equal, if not superior, air quality to conventional buildings will remove a current obstacle to the promotion of greater energy efficiency. Similarly, lowering the real and perceived energy penalty associated with higher rates of ventilation will remove an obstacle to improved indoor air quality.

The added cost of building for the needs of the hypersensitive, at least 20% higher than for standard construction, creates a serious affordability problem for such persons, who are often unemployable at this stage in their lives. Therefore, the challenge is to find more affordable means of providing "cleaner" housing. This can only come from efforts to standardize solutions as far as possible and to achieve some economy of scale. The prefabricated housing industry may have the ingredients for meeting this challenge. While the strong response to CMHC's survey suggests that the number vulnerable to hypersensitivities is significant, accurately estimating that number remains elusive, and it will probably remain unknown until workable definitions of hypersensitivity are developed by the medical profession. It has been suggested by advocates for the hypersensitive in Canada that as much as 6% of the population suffers in some way from hypersensitivities.

CONCLUSIONS

The results of CMHC's IAQ and building science research suggests that building envelopes and mechanical systems can be designed and built to maximize energy performance while minimizing the contribution of combustion gases, molds, soil gases, and material emissions to the indoor air. Therefore, energy conservation measures to be implemented in the future, as a response to growing environmental concerns, need to be undertaken within a "systems" approach to housing technology, in order to create housing that can be regarded as healthy for both the occupants and the global environment.

For the chemically hypersensitive, creating suitable housing that is also affordable remains a challenge due to the current degree of customization required. Source control of pollutants is ultimately much more effective than diluting pollutants through ventilation, and, therefore, research is required to develop "low-pollution" building materials, furnishings, and equipment.

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