MOISTURE CHALLENGES IN CANADIAN ENERGY EFFICIENT HOUSING

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ABSTRACT

The rapid evolution of traditional wood-frame construction practices, in response to the need for energy conservation, has led to an increase in moisture problems in some new and retrofitted houses in certain parts of Canada. This has prompted Canada Mortgage and Housing Corporation (CMHC), the federal government's housing agency, to undertake a detailed program of research, which has involved field surveys, test hut monitoring and computer modelling. After almost a decade of such research, a better understanding of the principles of moisture, air and heat flow has been gained. This improved understanding is now being translated into practical applications for energy-efficient housing to prevent or remedy moisture problems.

INTRODUCTION: AN HISTORICAL BACKGROUND

Canadian low-rise housing has traditionally used wood-frame construction due to its advantages of economy, durability, speed of erection, flexibility of design, ease of renovation, and availability and renewability of materials. As a traditional form of building, various practices developed, based primarily on observation, which were passed from one generation of builders and trades to the next. Such practices recognized and enhanced the "forgiving" nature of wood framing - its ability to withstand repeated cycles of wetting and drying, of temperature extremes and of minor structural movements. Because the system had successfully withstood the rigours of the Canadian climate and was well understood by trades and laymen alike, little research was undertaken to determine the limits of its performance.

From World War II until the early 1970s, gradual changes in wood-frame construction took place which resulted in greater airtightness and reduced heat loss, while more affluent lifestyles increased internal moisture generation. Meanwhile, the primary exhaust device, the chimney flue, was being used less frequently as furnaces became more efficient, or disappeared altogether in the case of electrically heated homes. The combination of these three factors brought a certain percentage of Canadian homes close to the limits of "forgiveness". With the rise in world energy prices in the 1970s, wood-frame construction practices evolved rapidly to facilitate higher insulation values and increased levels of airtightness. However, these changes were so rapid that many aspects of traditional good building practice and building science were overlooked. The result was a higher incidence of moisture problems, both in new and energy-retrofitted homes, and an unfortunate association between energy efficiency and moisture troubles.

Since conventional assumptions about Canadian housing indicated that there shouldn't be moisture problems, there was clearly a need to re-examine these assumptions and to take a more detailed look at moisture loading, air change rates, local surface temperatures, effective insulation values, typical construction practices and building code requirements. Canada Mortgage and Housing Corporation (CMHC), the federal government's housing agency, became involved in recognition of the importance of moisture control to the durability of the housing stock and of the potential impact of various energy conservation programs. More recently, two additional factors - increasing epidemiological evidence linking respiratory disease to dampness, and a renewed interest in energy conservation due to concern over the global warming - have reinforced the significance of this issue.

CMHC'S MOISTURE RESEARCH PROGRAM

Preliminary studies in the Atlantic provinces confirmed anecdotal reports provided by CMHC inspectors of moisture deterioration. This led to a major national survey in 1982 of housing which CMHC had financed or mortgaged. The results were extrapolated to predict that approximately 1% of the Canadian stock had moisture-related structural damage, while approximately 10% had moisture problems of some degree, such as excessive condensation, damage to interior or exterior finishes, or mould growth. (1)

CMHC therefore initiated a comprehensive research program to determine the underlying causes of moisture problems and to develop solutions. This work has included the investigation of numerous housing units in various parts of Canada; the construction of test hut facilities in several climate zones to monitor the long-term performance of various wall assemblies; the development of computer models to simulate moisture, air and energy movement in walls (WALLDRY) and roofs (ROOFDRY); and the implementation and testing of remedial measures. The purpose of this paper will be to highlight the findings and implications for typical Canadian wood-frame housing.

FINDINGS

The past ten year's work has yielded many useful results. Theoretical modelling, supported by field and lab observations, has led to an improved understanding of the inter-related causes of moisture problems in exterior walls, attic spaces, basements and crawl spaces. Highlights include:

Climatic factors: The 1982 national survey indicated that the frequency of moisture problems was very dependent on climate. Cool, damp climates with insufficient sunny periods to promote drying, such as in the Atlantic provinces and to a lesser degree on the West Coast, had the highest incidence. Northerly areas, with extremely low temperatures and short drying seasons, were also susceptible. In other parts of Canada, moisture problems were rare. Clearly, the "forgiving" nature of wood frame construction could be challenged by long periods of moisture accumulation within the building envelope combined with insufficient drying periods.

Internal moisture sources: While it was previously believed that Canadian houses were "too dry" and required winter humidification, the 1982 survey found most troubled houses had high levels of indoor relative humidity (45-85%). The sources of these high RH levels were not immediately apparent. Further studies by CMHC and the National Research Council (NRC) revealed "hidden" moisture sources not previously considered: the drying of construction materials, especially concrete foundations (4-5 L/day during the first year); certain occupant practices, such as the drying of firewood indoors (up to 5 L/day); seasonal storage of moisture by the house and its contents during humid summers and subsequent release in the fall and winter (3-8 L/day); and ground-related sources (2-50 L/day). (2) The magnitude of these latter two was not fully appreciated until the results of two projects on "internal moisture source strength" were completed. These revealed that increased ventilation rates could actually draw more moisture into the house (up to 100 L/day), especially in relatively airtight houses with leaky basements or crawl spaces. (3) Related research on "soil gas" (primarily because of concern over radon and methane) confirmed that the infiltration of saturated air from below grade contributes several per cent of the "fresh air" entering Canadian houses. (4)

External moisture sources: Houses with problems on east walls were once thought to provide evidence that exfiltration of moisture-laden air was the primary mechanism for moisture deposition in wall cavities, since the prevailing winds are from the west. Upon further study, it was noted that many storms involve easterly, rather than westerly winds, especially on the east coast, and so wind-driven rain could not be discounted as a moisture source. It has also been found that condensation ("morning dew") behind the cladding can be evaporated and driven into walls under solar effects.

Poor selection of materials: The deliberate use of wet framing lumber in the Atlantic test huts drew objections from the housing industry, who claimed that this was not realistic. However, a subsequent survey of various building sites in the Atlantic provinces revealed that more than 90% of framing lumber exceeded the 19% moisture content specified by the National Building Code, and more than 50% exceeded the fibre saturation point. (5) In addition to retarding the drying process, the use of such green lumber leads to loss of airtightness when the wood shrinks and warps.

Inappropriateness of certain wall assemblies: Test hut monitoring has indicated that certain combinations of materials, such as low permeability exterior sheathing with wet framing lumber, could lead to prolonged conditions of elevated wood moisture contents, which in turn could lead to fungal growth. (6) However, the materials themselves may perform quite adequately under other conditions. An illustrative example is that of wet-sprayed cellulose insulation. In the Atlantic test hut project, framing members in panels with wet-sprayed cellulose took by far the longest time (18-24 months) to dry to moisture contents below 19%. On the other hand, a subsequent project in Edmonton, Alberta found that walls with wet-sprayed cellulose dried to 19% MC within only 2-3 months, with virtually no evidence of fungal growth. (7) A closer examination revealed certain advantages in Edmonton's environment and building practices: a much drier and sunnier climate which speeds the drying process; the use of typically drier framing lumber (15% MC); the use of plywood sheathing which is more resistent to moisture cycling than the composite sheathing products common on the East Coast; and the use of less water in the cellulose application. The dilemma presented by these two projects is how building codes and inspectors can allow a product under certain conditions and disallow its use under others.

Inadequate construction practices: Numerous field observations have provided anecdotal evidence of poor detailing. Wind-washed minimal insulation at exterior corners, convective currents around poorly-placed or missing insulation, and the lack of a continuous air barrier at electrical outlets or floor/wall intersections can reduce local thermal resistance values by an order of magnitude, thereby causing condensation to take place in homes with relatively low RH. In addition, poor siding and flashing practices can allow rain and snow to penetrate the envelope, while inadequate grading around the house perimeter can contribute to basement leakage. The use of exterior drainage-type insulation has been identified as a key to improving the performance of foundations with respect to moisture. (8) Test hut work has led to recommendations for assisting the drying process through the use of permeable sheathings and ventilated air spaces behind wood-based claddings. (9) Airtightness testing of various wall components and assemblies has demonstrated the need for air barriers and their joints to be structurally supported for durability under repeated pressure cycling, in order to reduce both the exfiltration of moisture-laden air and the infiltration of wind-driven rain and snow. (10)

Inadequate code interpretation: The requirements or enforcement of building codes may support accepted practices, while inadvertently violating building science principles. A study of basement condensation problems in new homes in Winnipeg, Manitoba provided a landmark example. The combination of typical overwatering and inadequate curing of concrete foundations, thermal lag in ground temperatures, and the placement of insulation on the interior of basement walls was found to make the occurence of summer condensation on foundation walls virtually inevitable in cold climates such as Winnipeg's. (11) Delaying the finishing of basement walls for approximately a year, to allow the concrete to dry, would permit any future condensation to be absorbed by the concrete, but represents a departure from code requirements. Similarly, a study of crawl space moisture problems in northern Manitoba identified the sill plate, which connects the floor framing to the foundation, as an "Achilles heel" in terms of inevitable condensation. (12)

Lack of general ventilation: In response to controversy over a proposed ventilation standard, a national airtightness survey of typical new homes in 1989 confirmed that Canadian housing had become 30% tighter since 1982-83, and that only 40% of new units had adequate ventilation systems. (13) While passive stacks have been demonstrated to be effective in certain situations for reducing excessive indoor RH levels, preliminary analysis (arising from separate work on combustion venting) has suggested that passive ventilation systems are too dependent upon wind to provide reliable moisture control. With respect to mechanical ventilation, in-situ testing of actual air flows has found that typical fans exhaust air at only half their rated performance, primarily due to poor installation of fans and ducting. (14)

Ventilation as a moisture source in attics and crawl spaces: The study of crawl spaces in northern Manitoba also revealed that the ventilation of crawl spaces, as required by codes, can actually increase the moisture content of framing lumber in the spring and summer, again because of thermal lag in ground temperatures. Similarly, the required ventilation of attic spaces may solve moisture problems in some cases, but worsen them in others. Protocols have been developed to determine attic airtightness and air change rates for a current survey of attics which is identifying the necessary conditions for attic ventilation to be effective. In summary, the use of ventilation for moisture control is only effective where sufficient drying potential exists.

Gaps in building science: The development of the WALLDRY model has exposed areas where the knowledge base is incomplete or inaccurate. There is a need for more accurate information on moisture movement through materials under thermal gradients, material properties under saturated conditions, wetting rates under surface-wet conditions, and surface drainage characteristics. (15) Initial validation of WALLDRY against field data has suggested that some property constants may need to be modified by factors as high as 4. Model development has also required the determination of time constants for air, moisture and heat flows, since data generated from test huts and simulations have confirmed that exterior walls never reach steady-state conditions, but continually demonstrate dynamic processes whose time constants may range from hundredths of seconds to several hours. Diurnal cycles were found to be particularly significant, with moisture cycling back and forth through the envelope under the alternating effects of solar and night sky radiation, analogous to a heat pipe. WALLDRY has successfully predicted the accumulation of moisture, as a result of such dynamic cycling, in a susceptible mid-height zone in single storey walls, a phenomenon which has often been noted in field observations, but not fully understood. (16)

MAJOR CONCLUSIONS AND DIRECTIONS FOR EFFECTING CHANGE

After 10 years of research, CMHC has developed an improved understanding of the complex relationships between energy and moisture in low-rise housing. The primary conclusion is that moisture problems can occur where the "threshold" limit of wood-frame construction is exceeded by the combination of three factors: high internal and/or external moisture sources, insufficient moisture removal through drying or ventilation, and cold local surface temperatures. While work continues on monitoring test huts in other climate zones, upgrading the moisture models and utilizing them to predict optimum moisture and energy performance, sufficient work has been completed to put forward some specific recommendations.

Moisture source control: The variable success of ventilation as a solution to moisture problems, combined with the associated energy penalty, leads to a preference for reducing moisture sources. Such source control is primarily an issue of homeowner and builder education. Code requirements can also assist; for example, CMHC recommended changes to the 1990 National Building Code regarding the sealing of basements to prevent soil gas entry.

Improved envelope detailing: The training of designers, builders and trades needs to focus on building practices which can reduce localized cold surfaces through more effective insulating techniques and through the minimization of air leakage paths. "Moisture Problems" has proved to be one of the most popular modules in the Builders' Workshop Series developed by CMHC.

"Intelligent" ventilation systems: The phenomenon of moisture storage within buildings, combined with the varying drying potential of outdoor air, suggests that ventilation, especially of attics and crawl spaces, be controlled by sensors which analyze both indoor and outdoor conditions.

Variability and the need for modelling: The great variability in climate, house design, building materials and construction techniques makes it difficult to predict moisture and energy performance. Since it is not feasible to build test huts of every possible configuration in every climate zone, computer modelling becomes an important tool to predict performance under a variey of conditions, to provide advice to industry and code officials, and to better target lab and field testing.

Regional application of building codes: Such variability also underscores the need for prescriptive building codes and standards to be modified or interpretted on a regional basis in a manner which is sensitive to local differences in climate, design, material selection and building practice.

The need for a "systems approach" to energy and moisture: Air sealing can reduce interstitial condensation, while increasing interior RH levels; higher levels of insulation can eliminate cold interior surfaces, while also reducing the drying potential of wall cavities and attics; exterior basement insulation can keep foundations dry, while interior basement insulation can make condensation inevitable. Clearly, energy conservation measures can be both a cause of, and a solution to, moisture problems. Individual manufacturers and trades are often unaware of the impact of their products or work on others. It is therefore necessary that research activities, information transfer programs and code development utilize a "systems approach" which considers the complex interactions among the building envelope, mechanical systems, ground conditions, exterior environment, interior environment and occupant lifestyle. It is only through such a systems approach that the "forgiving" nature of wood-frame construction can be enhanced, and the two objectives of energy conservation and building durability can be satisfactorily harmonized.

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