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Conclusions from Ten Years of Canadian Attic Research

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ABSTRACT

Canada Mortgage and Housing Corporation (CMHC) conducted a series of attic research projects from 1988 to 1997. Initially, there were few field test data to substantiate how attics dealt with air and moisture transfer. The CMHC research developed a test protocol for attic airtightness and air change testing and then proceeded to field testing of a variety of attics in different climatic areas. An attic model, ATTIX, was referenced against test hut data and used to simulate attic performance across Canada. The latest research project compared the performance of nominally identical attics, one of each pair with full, code-required venting and one with all intentional holes sealed.

Results show that ventilation plays a relatively small part in the control of attic moisture and temperature but, conversely, rarely provokes major moisture problems. This suggests that there is no significant advantage in changing current Canadian attic code requirements, except perhaps by allowing more flexibility in venting design.

INTRODUCTION

Most people believe that ventilating attic spaces is critical to remove heat in summer and moisture in winter. It has only been in the last ten years that building researchers investigated attic heat and moisture transfer more rigorously. What they have found tends to downplay the traditional importance assigned to attic ventilation.

Canada Mortgage and Housing Corporation (CMHC) is the federal department responsible for housing research. In 1988, it started a series of attic venting and moisture research projects (see list of CMHC published reports in References) that culminated in 1997 with field testing in Vancouver and Edmonton. The work up to 1991 has been summarized in a paper presented to the Building Thermal Envelope Coordinating Council (BTECC) at their 1991 workshop "Bugs, Mold & Rot" (Fugler 1991).

CMHC research was prompted by recommendations in a consultant's report on ventilation in Atlantic Canada. Upon discovering wet attic sheathing, the consultant recommended an increase in attic venting. To anyone familiar with coastal climates, the concept of drying out an attic with cold fog seemed inappropriate. The incongruity of the advice prompted CMHC researchers to look into existing attic ventilation and moisture models (Cleary 1985; Gorman 1987). The models indicated that the amount of moisture removal by cold winter air was relatively minimal compared to the moisture removal and storage by attic wood members.

There was a dearth of attic ventilation rate test results to input into models. CMHC developed test protocols for attic air change rate and airtightness testing, then tested 20 houses under a variety of conditions. Researchers at a Canadian university continued development of the Gorman attic model (Gorman 1987), eventually integrating it with their Alberta Infiltration Model (AIM). They also used the test houses for repetitive attic ventilation rate testing and model verification. Finally, a consultant tested new homes built with and without attic ventilation to observe the consequences of omitting all intentional attic ventilation for new houses. The CMHC research benefited from communication with other attic researchers, notably Anton TenWolde (TenWolde and Carll 1992) and Bill Rose (1992).

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Following is a summary of the major findings of the CMHC attic research program, with an emphasis on the post-1991 projects.

HIGHLIGHTS OF RESEARCH PROJECTS

Survey of Moisture Levels in Attics (1991)

Using the attic air change and airtightness test methods developed for CMHC (BLP 1989; Sheltair 1989), a consultant tested 15 houses in Ottawa, Ontario, and 5 houses in Prince Edward Island on the Atlantic coast. House airtightness testing included establishing the interface leakage area or the size of the openings linking the house with the attic air. All houses had two attic air change tests, in winter and summer, and five houses had six air change tests. Wood moisture measurements were taken monthly from November 1989 to October 1990 using six permanently installed pairs of moisture pins located on gables, ceiling joists or lower truss chords, and rafters or top truss chords. Sheathing moisture content was manually sampled using a wood moisture surface probe. The consultants estimated the intentional attic ventilation openings and then calculated this area from blower door testing.

This study provided the first on-site measurement of the characteristics of a large number of northern attics. Results are described in two CMHC reports, with the appendices providing the greater amount of detail on individual houses (BLP 1991). The measured intentional venting area had an average equivalent leakage area (ELA_{10}) of about 3000 cm^2 (465 $in.^2$), with a range from 800 cm^2 (125 $in.^2$) to "too loose to measure." The ELA_{10} definition is from the Canadian General Standards Board procedure for airtightness testing (CGSB 1986). Measured ventilation areas were usually within ±50% of the estimated areas, with two houses having estimated areas over 200% greater than the measured areas, presumably due to blocked venting or perforated metal soffit applied over existing sheathing. The attic interface leakage areas were fairly uniform, with an average ELA_{10} of 330 cm^2 (51 $in.^2$) One tightly built, R-2000 house had an interface leakage area of 20 cm^2 (3 $in.^2$). Because these leakage areas are derived using subtraction (i.e., house ELA including the attic interface minus house ELA with attic equally depressurized)—with the inaccuracies inherent in such a procedure—the results should be considered an indication of the order of magnitude of interface leakage area rather than a precise measurement. Attic air change measurements are shown in Figure 1.

Attic air change rates are much higher than house air change rates, which, in Canada, tend to be within the 0.2-1.0 air changes per hour range. Of the attics with six air change tests, some had consistently low air change rates, some consistently high, and some with a wide variation. There was no particular correlation with wind effects in this small sample. For a discussion of wind and stack effects on attic ventilation, see the Alberta attic testing below.

Wood moisture contents in the attics showed a similar pattern in most houses. Midsummer wood moisture contents

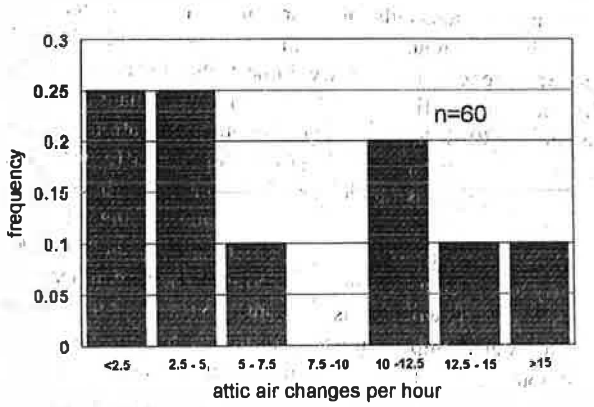

Figure 1 *Binned attic air change test results.*

were 10%-15% throughout the attic. Most attics showed a rise in wood moisture content (MC) through the fall and winter, with a drop to near 10% in April or May. Sheathing moisture contents were the highest measured, some reaching over 60% MC during midwinter. The seasonal increases in moisture content on the gables, trusses, or rafters tended to be more modest (see Figures 2 and 3).

Alberta Test Houses and Modeling

A series of six, single-story test houses are located near a university campus in Edmonton, Alberta. Two of the houses were monitored for attic air change rates from 1990 to 1992,

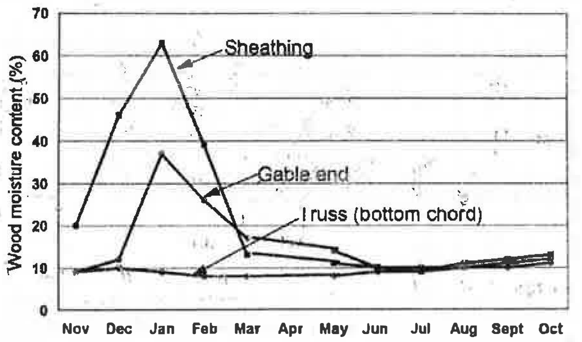

Figure 2 *Attic wood moisture content for "wet" attic.*

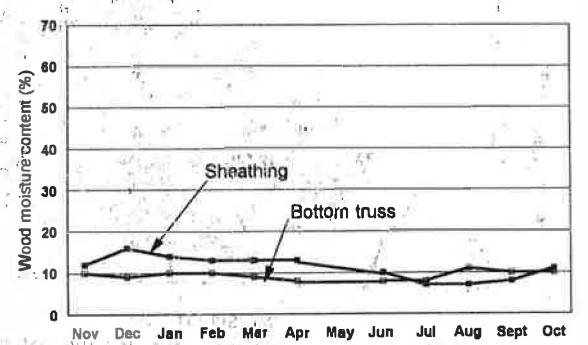

Figure 3 *Attic wood moisture content for "dry" attic.*

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resulting in thousands of hours of well-documented data collection. The houses are 6.7 m × 7.3 m (22 ft × 24 ft), with gable roofs enclosing an attic volume of about 61 m^3 (2200 ft^3). One attic had soffit and roof vents to approximate the code-required 1:300 rule (NBC 1995) for attic ventilation (attic 6). The other attic had all intentional openings sealed (attic 5). The attics were tested using blower doors to calculate the interface and attic leakage areas. Tracer gas air change testing was virtually continuous during the test period, with a resulting 4000 hourly averaged air change data points. The researchers also monitored attic wood moisture contents as well as the relative humidity and temperature of attic air. A weather station by the test houses logged wind and outside temperature.

The collected data provide a comprehensive data set for ventilation rate modeling (Forest and Walker 1993). It also provides insight into why the attic air change test results in the Ottawa testing seemed so unpredictable. Figure 4a shows the measured attic ventilation rates for attic 5, which have a trend to increasing ventilation rates with increasing wind speed. Figure 4b shows the same graph generated for attic 6, which had more than three times the attic leakage area and produced correspondingly higher ventilation rates. Looking at Figure 4, one can see that at any wind speed above 3 m/s (10 ft/s), the range of possible attic ventilation rates will vary widely. Choosing a random six points on Figure 4, as was effectively done in the earlier CMHC attic testing, shows no particular correlation of attic air change with wind speed.

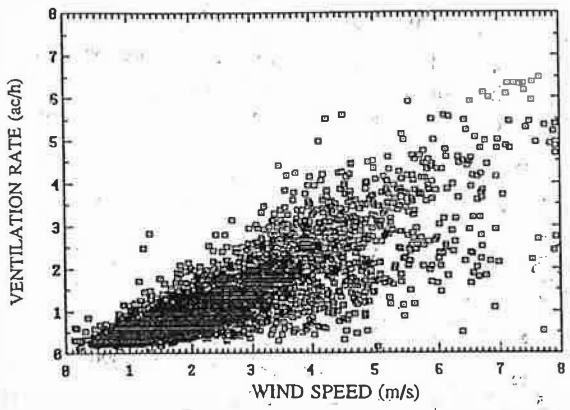

Figure 4a Attic 5 ventilation rate graphed against wind speed.

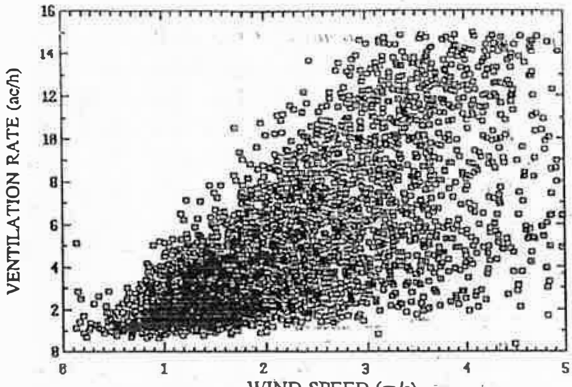

Figure 4b Attic 6 ventilation rate graphed against wind speed.

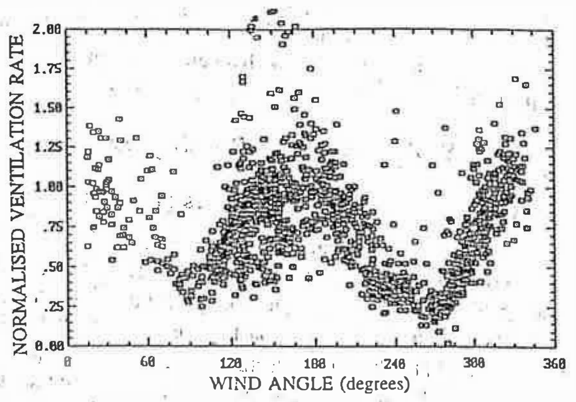

Figure 5 Attic 5 normalized ventilation rate against wind direction.

Figure 5 shows the normalized attic 5 ventilation rate (actual attic ventilation rate divided by mean attic ventilation rate) when plotted against wind direction. On this graph, 0° is north. The six test houses are oriented in an east-west row so that there is little wind shielding from north or south winds and significant wind shielding from adjacent buildings for east or west winds.

This wind direction dependency of the attic ventilation rate is quite clear on these attics. However, these test attics are in an open prairie setting, with definable wind shielding characteristics. For normal houses in urban or suburban environments, or for rural houses surrounded by high vegetation, wind shielding is far harder to predict or model. If you separate out for attic 5 only the southern winds, the measured attic ventilation rates are correlated quite well with the wind speed, especially compared to the entire wind spectrum presented in Figure 2. See Figure 6 for the performance of attic 5 with southern winds.

Another aspect of the attic ventilation rate equation is the effect of thermal buoyancy on attic air change. The graph presented in Figure 7 shows the range of attic ventilation rates for attic-outdoor temperature differences of 0°C-30°C (0°F-54°F), all for winds less than 2 m/s (6.6 ft/s). It is clear when comparing this graph to the others that stack effects are not as important and may be less predictable than the wind effects shown above. There may be another attic temperature (e.g., sheathing temperature) that better correlates ventilation rates and buoyancy effects. There are few attic air change rates above 1.0 air changes per hour, no matter what the temperature difference.

Figure 8 shows the measured diurnal variation of attic temperatures for 10-11 April 1991. Note that the attic air temperature is significantly warmer than the outdoor air temperature, with the difference increasing midday. Exterior sheathing temperatures are warm (>40°C or >104°F) despite

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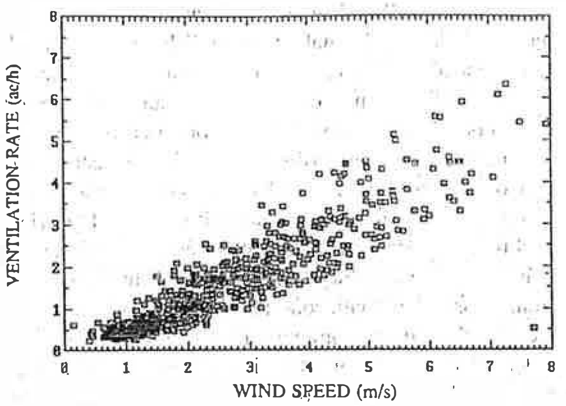

Figure 6 *Attic 5 ventilation rate for south winds only* (n = *641 points).*

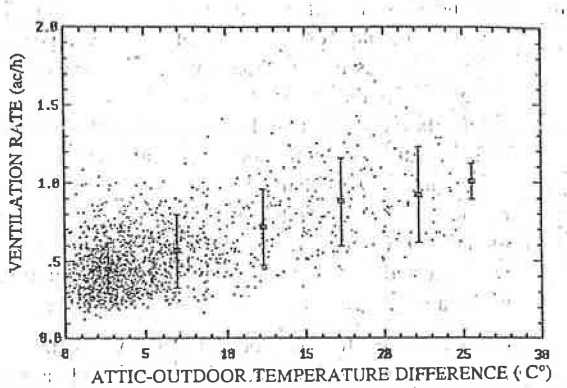

Figure 7 *Attic 5 ventilation rates for all wind speeds less than 2 m/s* (n = *1573).*

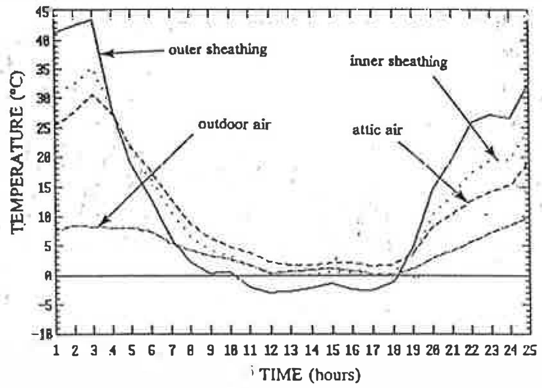

Figure 8 *Diurnal variations in attic 6 (hour 1 is noon).*

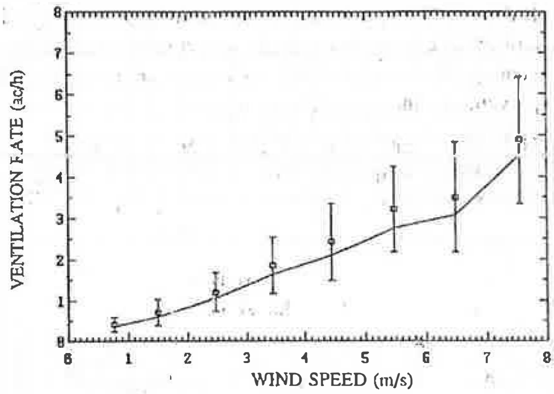

Figure 9 *Comparison of ATTIX predictions with measured ventilation rates.*

the maximum outside air temperature of 10°C (50°F). The sheathing temperature also drops in the evening to a temperature cooler than outside air, due to night sky radiation, and will likely cause incidents of condensation or frosting on the sheathing. The swings in sheathing temperature will affect its moisture content on a daily basis. Truss temperatures (not shown) follow the attic air temperatures.

A two-zone ventilation model was developed that included ventilation rates for the house and the attic based on the air change modeling of Wilson and Walker. A more comprehensive attic model, ATTIX, incorporated thermal and moisture modeling. Interested readers should consult the full CMHC report for details of model development (Forest and Walker 1993). Iain Walker ran ATTIX using the same input conditions recorded for the test houses and compared the predicted results for ventilation rates, temperature, humidity, and wood moisture content. Figure 9 compares the predicted vs. measured ventilation rates of attic 5 for all wind directions and temperatures. The difference between the measured values (as indicated by the data points) and the predictions (shown as the line) increases with increasing wind speed.

Similarly, Figure 10 shows the difference between the measured and predicted (dashed line) vapor pressure in attic 6 for a six-day period in May 1991. Agreement is rough. Data analysis on the attic vapor pressures showed that the mean error for various seasons range from −8% to −20%, with percentage differences highest in winter when vapor pressures are low. Absolute attic air vapor pressure differences ranged from 13% to 21%.

Having created a model of adequate accuracy, the researchers simulated attics in different climates with different construction details and with different types of ventilation. Both reports (Forest and Walker 1993; Forest and Berg 1993) describe investigations using the model to predict attic wood moisture contents. In some cases, ventilation fans were used instead of passive ventilation openings in the expectation that these could be activated when drying conditions were optimum. Conclusions from these two studies include:

1. Attic air moisture conditions are affected by both the air infiltrating from the house and the outside ventilation air. Moisture from the house dominates when the attic is well sealed or ventilation rates are low.

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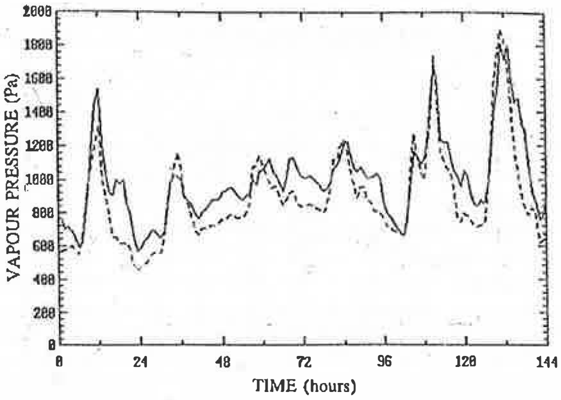

Figure 10 Measured vs. modeled attic air vapor pressures.

2. If there is a significant leakage rate from the house to the attic and the house is in an area with cold winters, the 1:300 venting ratio does provide the attic ventilation necessary to prevent substantial winter icing.
3. High attic ventilation rates will increase wood moisture content in maritime climates, especially during spring and fall. The 1:300 venting ratio may be excessive for these climates.
4. Mechanical ventilation, if used as a substitute for passive vents, should consist of a fan supplying air into the attic at a rate of roughly 5 air changes per hour.
5. The ATTIX model would benefit from better wind pressure coefficients and wood moisture relationships at temperatures below freezing. The treatment of condensed water in the model needs further examination.

British Columbia Modeling and Field Studies

The last major attic project conducted by CMHC was to take the results of this prior research and use them in field testing of new and existing houses. The intent was to use ATTIX to aid in the design of vent requirements for new housing and to suggest remedies for several existing houses with observed moisture problems. The planned research soon ran into difficulties for the following reasons:

1. The contractor could not locate a sufficient number of attics with existing moisture problems within his region.
2. There were uncertainties about measured wood moisture contents in the attics, using moisture pins or "Duff gauges," and how these related to the predicted wood moisture contents produced by the ATTIX model. Trends were in the right direction; absolute moisture contents were different.
3. ATTIX was not as flexible in modeling individual houses as anticipated, and its use by the contractor revealed some programming oversights (e.g., house orientation did not affect the modeled results). The author of the original model was hired to remedy some of the ATTIX shortcomings.

Despite the ATTIX upgrading that occurred during the project, there was no formal report published on the modeling results. Instead, a CMHC report was issued (Sheltair 1997) that described only the houses sampled and their field test results. Four pairs of houses were monitored over a winter: two pairs in Vancouver, British Columbia, a coastal climate, and two pairs in Edmonton, Alberta, a cold interior climate. All houses had open, trussed attics with plywood or oriented strand board sheathing and asphalt shingles. Roof shape and orientation differed. Each pair of the Edmonton houses contained one house with code-required attic venting (labeled as "Control") and one nominally identical house by the same builder with all intentional ventilation openings sealed. The same concept was used in the Vancouver houses except that V1 and V1 Control were the two halves of a building with two semi-detached houses, and V2 and V2 Control were separated attics of the same large house. The builders were instructed to ensure that the house-to-attic interface in each sealed building was as tight as possible. Testing of the interface leakage areas showed that there was no consistent trend to improved attic interface tightness in these paired houses, even if the builders had made efforts to construct tight interfaces. Each of the eight houses was measured manually, once a month, from September 1996 to March 1997 with hand-held, resistance measuring moisture meters for all orientations at two different wood penetration depths (3 mm and 9 mm or 0.12 in. and 0.35 in.). The crew also tested house and attic temperature and humidity, plus outdoor ambient conditions at the time of the test.

The results echo the previous testing. Attic sheathing moisture contents were higher than other attic wood moisture contents, in part due to the effects of night sky radiation where the sheathing would reach dew point temperatures more frequently than the framing members. The sheathing moisture contents showed an increase through the winter, followed by a drop in the March readings. Of the four pairs of houses, two of the sealed attics showed marginally higher midwinter moisture contents than their vented counterparts, and two sealed attics showed marginally lower moisture contents. Three of the paired attics (V2, E1, E2, and their controls) were very dry, with the measured north sheathing moisture contents never exceeding 20% MC. Both of the V1 attics exceeded 25% and showed a different moisture content profile than the three other pairs (see Figure 11).

The contractors concluded the following from this project, albeit from a small sample:

1. The elimination of intentional attic ventilation in the houses studied did not result in large differences of attic moisture content between the code attics and those with vents sealed.
2. The houses with higher indoor relative humidities showed higher attic wood moisture contents in this sample.
3. The differences in measured interface leakage areas did not correlate directly with observed attic wood moisture contents.

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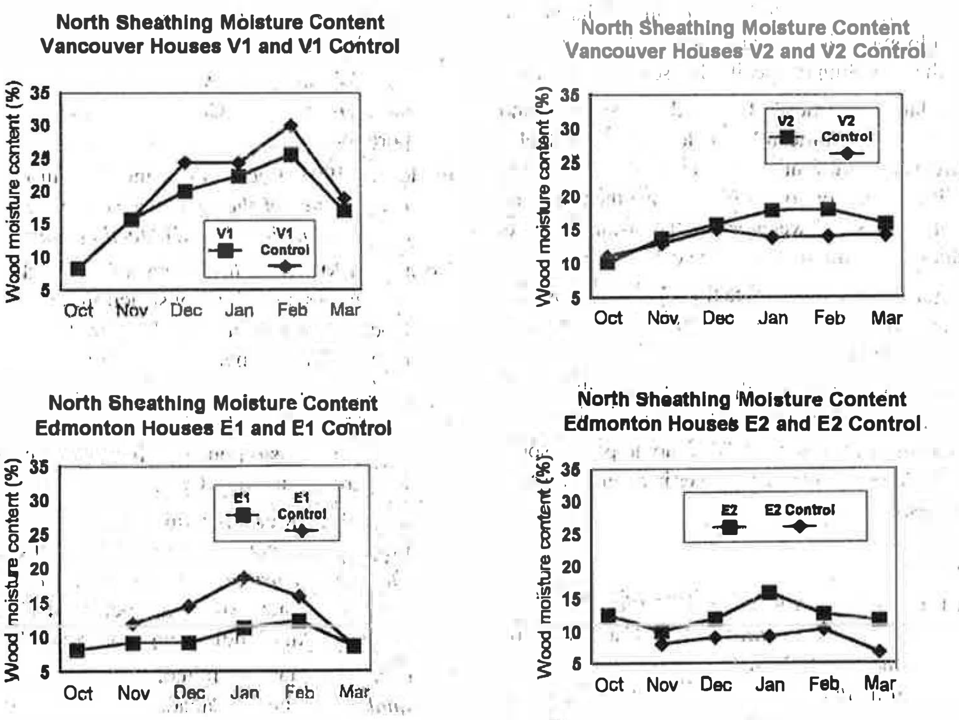

Figure 11 Measured wood moisture contents in the north sheathing of the four paired attics.

4. Wood moisture contents were low in the Edmonton attics despite the occasional observed frosting of the sheathing.

Ice Dam Research

CMHC conducted one other attic-related project during the winter of 1995-96 in the Ottawa area. In that winter, several Canadian cities (Ottawa, Montreal, Winnipeg, and others) had weather conditions in late fall conducive to the creation of ice dams on roofs. There was an abundance of snowfall, no pronounced thaws, and a daytime temperature range of roughly –10°C to 0°C (14°F to 32°F). Such conditions foster the development of ice dams, and their occurrence was epidemic.

Curiously, new houses seemed to be affected as well as older dwellings, despite good air sealing, high levels of attic insulation, code-required venting, and waterproofing membranes under the first several courses of asphalt shingles. A contractor surveyed several hundred new houses in the Ottawa area, visually sorting them into houses with or without severe ice damming. From these houses, 16 houses with obvious ice dams and 17 houses relatively free of ice damming were studied. The contractor performed a visual inspection of the attic and house and left a remote temperature sensor in the attic that was read and recorded by the householders for several weeks. CMHC published a report on this work (Scanada 1996). The clearest differences between the houses with ice dams and without ice dams included the following.

1. The majority of houses with ice dams were row houses. Those without ice dams were largely single, detached houses. The row houses in the survey generally had less (observable) attic ventilation, especially through the soffits, and more interior chimneys and concrete block party walls. All these factors could contribute to increased ice damming.

2. The houses with ice dams typically had warmer attics than those without ice dams. On a day with a mean outside temperature of –6°C (21°F), the ice damming attics were on average 4°C (7°F) warmer than those without ice dams.

3. Attics with ice dams were more apt to have lower levels of insulation, unsealed attic hatches, and peculiar architectural details on the roofs. The sample size was not big enough to quantify these effects.

Based on this set of research findings, CMHC advice to homeowners with attic moisture problems or ice damming will first suggest reducing the possible house influence on the attic (heat, air, or moisture flows from the house to the attic) prior to trying additional ventilation measures. A document designed for consumers, reflecting this advice, is in production (CMHC 1998).

CONCLUSIONS

1. Canadian attic ventilation and moisture characteristics have been established through field testing over the last decade.

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2. An attic simulation computer model, ATTIX, has been developed and used for parametric modeling. At its current stage of development, it is suitable as a research tool only and not for the modeling of specific houses or situations.
3. Natural ventilation of attics is largely dependent on wind speed and will vary significantly due to local wind shielding. The effects of attic ventilation on attic wood moisture contents will change from one climate to another. In some areas, primarily coastal, lower attic wood moisture contents may be achieved by minimizing attic ventilation rates.
4. Minimization of heat and moisture flows from the house to the attic seems to be a prudent way of reducing ice damming and attic moisture problems.
5. Despite the above conclusions, there is no compelling case to be made for reducing code requirements for attic ventilation of new houses. However, codes should permit some flexibility in design to allow alternatives in controlling attic moisture levels.

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