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Wet Walls: Apparent Incidence of Excessive Condensation in House Envelope Construction in Canada

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A B S T R A C T

Following extensive field work for private industry, particularly concerning troubled new housing on the east coast, Scanada conducted surveys across the whole of Canada. A 14,000-house sample was scanned thermographically, covering all ages of urban-suburban stock. In a separate survey, 1,900 older houses retrofitted with wall insulation were moisture-probed (with electrical resistance meters) in ten points each around the sole plate. The surveys and direct field work all suggest that about 15% of new and old houses in windy, cold east coast areas, especially in Newfoundland, appear to have at least small areas of excessive moisture in their walls. The moisture accumulations appear to be mainly from exfiltrating air through envelope leaks (especially hidden leaks in structural junctions), and are biased somewhat to the lee side of prevailing winter winds. Leaky window sill details are also common contributors allowing entry of rain as well as indoor condensate into the walls. Inland, across populated Canada, the wet-wall incidence falls to 1 - 3% and even less. The moisture problems are all seen to be more common or more severe where indoor humidity is at least moderately high in winter; electric heating or other "flueless" or slow-air-change characteristics are hallmarks of the great majority of the troubled stock. Further studies now underway, commissioned by Energy, Mines and Resources Canada, are determining the means of assessing and avoiding these and other moisture problems particularly as Canada's housing stock is more extensively retrofitted to conserve energy. The resulting approach to guideline development is discussed in the author's second paper in this symposium.

INTRODUCTION AND SCOPE

The great majority of houses across inland Canada apparently remain free of substantial moisture problems. Under the adverse climatic conditions of the coastal regions, however, a substantial fraction of houses sustain moisture accumulations serious enough to cause disfigurement or even structural damage. Modern coastal housing with flueless heating is especially prone to a wide range of such problems. As the older stock becomes more extensively "energy retrofitted", it also invites an increasing incidence and severity of moisture damage, particularly in coastal regimes and most particularly if the retrofitting includes conversion to essentially flueless heating. Materials manufacturers in Canada, and more recently our government agencies as well, have conducted field surveys and case studies to determine the nature and incidence of such problems and thereby to develop practicable guidelines on how to correct them now and how to avoid them ahead as we continue the "energy upgrading" of our housing stock. In particular, Energy, Mines and Resources Canada has commissioned a case study approach to the problem to develop guidelines on problem avoidance.

This paper reviews the findings on the incidence of moisture problems, particularly those of excessive moisture hidden in the house envelope, which can escape detection until damage is done. That is particularly true of wall cavity moisture, which fortunately is the rarest trouble maker but even it is too prevalent in certain coastal areas. The collective observations suggest a pattern, a working concept of critical conditions, that becomes a basis for development of guidelines on avoidance or correction of moisture problems. In a second paper in this BTECC Symposium (Developing Guidelines for Avoiding Moisture Problem in Energy Retrofit), the basis is developed and built upon. In all of this, we suggest that the phenomena are somewhat similar, and thus the findings are generally applicable, in all "cold country" regions whose climates are within the wide range of Canada's climates from east coast through prairies to west coast. We have seen some of the problem and its correctability or avoidability in the northern USA, northern Japan, Scotland, Scandinavia, and even southern-most New Zealand. We think that this work is broadly useful and this international symposium will help put it to full use.

FIELD SURVEYS: THE INCIDENCE OF THE PROBLEM BEGINS TO BECOME CLEAR

The literature describing the extent of moisture problems in Canadian houses is limited, particularly concerning retrofitted stock. Only "wet wall" incidence has been the subject of broad surveys, not dependent upon complaint reports, and these surveys have not been definitive. The two wet wall surveys[1] are described in the following paragraphs.

In the 1981 survey of 1900 houses, randomly selected from the older stock with walls retrofit-insulated, framing moisture content was measured at ten points around the base of the walls of each house. Where at least two of the ten points were found well above normal in moisture content (i.e. where the wood stud, sole plate, inner sheathing face and/or planking may have been approaching, or in some cases were exceeding, the fibre saturation point), that house was counted as a "wet wall" case. The survey itself was done in October, when it would be expected that all but severe accumulations of condensate from the previous winter would have dissipated. (Essentially no comparative investigation of walls was made in houses having no insulation or no retrofitted insulation.)

In March, 1982, a 14,000-house thermography/photography survey was conducted from the street in 13 metropolitan centres across Canada. It also yielded a picture of apparent "wet wall" incidence in older housing stock, much of it probably retro-insulated, and in the newer housing stock as well. The survey was laid out to be representative of the metropolitan housing stock by age group. The apparent incidence was rather similar to that found in the 1900-house moisture probing, but again there has been no attempt made to isolate an energy retrofit effect by itself, i.e. there has been no differentiation between insulated and uninsulated stock.

This latter survey was done in early spring, when winter accumulations of condensate would be assumed to be at their peak. "Wet walls" in this case were defined as only those walls having many patches or extensive spreads of apparently saturated areas, not just a spot or two. A word of caution: later thermography work has shown that latent heat effects can result in incorrect interpretation of thermography during freezing or thawing periods, so that the findings may understate the incidence of wet areas in the walls but certainly may overstate the apparent quantity of water. Brick veneers in particular can confuse the interpretability of the images. Further, uninsulated walls may also mask the presence of water. Nevertheless it is instructive to chart the findings of both surveys together as shown in Figures 1 and 2, emphasizing however that neither study sheds much light on the extent and seriousness of the apparent wetting within the wall structure.

VanPoorten[2] found an apparent incidence of general moisture complaints in 1973-1981 houses built under the National Housing Act of about 1.5% on a total cross-Canada basis. Indoor surface condensation accounted for the majority of problems, followed by roof space moisture. Eighty one percent of such houses were electrically heated and essentially flueless. Most of the remainder were reported to use airtight wood stoves and could also be considered relatively "flueless". The proportion of houses reporting moisture problems was very much higher in Newfoundland than elsewhere, just as in the two field surveys described earlier. Some of the stock was retrofitted but the effect of this can not be isolated with confidence, nor can extrapolations be made to predict the effect of increasing conversions to flueless heating.

The problems in the 1979-1981 portion of Canada's stock covered by VanPoorten were probably under-reported, since experience suggests that it takes two to five years for problems to build up and engender complaints. Hence we can surmise that the incidence of tangible complaints, in that stock, might now be 3% or more.

The concern about inviting wall condensation solely by retro-insulating older frame walls (lacking any separate vapour barriers) has been addressed reassuringly by Tsongas[3]. He opened walls in 79 houses which had been retro-insulated with cellulose, rock wool or glass fibre, and 29 uninsulated controls, in Spokane, Washington (6,835 Fahrenheit degree days). Essentially no moisture was found in either sampling, excepting in a few cases clearly wetted from water leaks (gutters, roofs, bathrooms). Wang[4] had found essentially the same results in 70 houses in northern USA and Canada.

FIELD EXPERIENCE: THE NATURE OF THE PROBLEM BEGINS TO SHOW

Individual case studies and complaint investigations are not very helpful in assessing the incidence of moisture problems, but they can be useful indeed in determining their nature and the cause-effect mechanisms and relationships. First we will review our most recent experience particulary in inland Canada, and then relay the observations of several other engineers, researchers and contractors from coast to coast. In addition to drawing heavily from John McKenzie's work, as will be ascribed, we have learned from the experience and judgement of J. Herenga, J. Drover and P. Gravelle in Newfoundland; D. Scott in Halifax; K. Ruest re. Quebec duplexes; T. Woods in Toronto; D. Bailey re. southern Ontario row houses; J. Hockman in Winnipeg, D. Jennings, D. Eyre and R. Dumont in Saskatoon; M. Baker, C. Mattock and K. Cooper in Vancouver.

Retro-Insulated House Walls Opened to View. The period of paranoia about UFFI (Urea Formaldehyde Foam Insulation) in Canada has engendered considerable activity in removing the material from houses. Whatever else it has accomplished, the activity has provided an unusual opportunity to examine the wall structures opened to view. Scanada and a co-worker on that project, Technitrol in Montreal, have attempted to learn of such removal activity and observe the opened walls whenever and wherever possible, especially in Quebec but also in Ontario, British Columbia and northern USA in some instances.

These inspections provided an excellent opportunity to learn about the state of our retro-insulated house structures. We did not select or bias our "sampling" in any way; just observed as many cases as we could find, over 110. In the majority of cases the walls were stripped and insulation removed from the exterior. In addition, 12 uninsulated older homes were examined with walls opened to view (during renovation or demolition work).

(As a point of considerable interest, we were able to observe the in-situ condition of the UFFI in more than half of the cases, arriving on site before it had all been removed. It had generally filled even difficult cavities rather completely, exhibited acceptably little shrinkage - usually under 5% linear - in almost all cases, and clearly had not deteriorated in any visible or tangible sense.)

The primary focus was on moisture effects of whatever origin. We searched carefully for wet spots or any signs of water damage in the wood wall structures, with the structure generally open to full view. Very few were found. The few minor spots of wood rot (found in only 12 houses) appeared old - predating the UFFI installation - and did not show wetness or signs of recent spreading. These few spots were found under window sills without proper drip edges, or at the junction of the wood structure with the foundation. The single rotted area that was found still wet was found abutting a leaky bathtub junction (an Ontario wood frame house). In all other cases, the wood frame structures, sheathing and planking were seen to be sound.

The same picture was revealed in the inspections of opened walls of uninsulated houses: moisture was very rarely a significant problem, and its infrequent effects followed the same pattern as above.

In watching for signs of any fungus, wood rot or other, special attention was paid to areas where the UFFI had been in direct contact with the wood (and those where sheathing paper alone had separated the two). We watched for fungus in any rotted spots, of course, but were more concerned about possible spreads of live fungus over wider surface area. None was found. In the rare spots of rotted wood the fungus appeared old, dry and apparently dormant. Again, the observations on uninsulated or non-UFFI walls revealed the same picture: essentially no problems.

The inspectors looked carefully for any signs of metal corrosion as well. Galvanized steel electrical boxes and brick ties revealed no signs of significant corrosion, whether or not in contact with the insulation. In Quebec's plank frame houses, common nails have been used as ties for brick veneer for generations. In 21 of the 32 such cases, some of these nails showed surface corrosion and some showed deeper corrosion, but only in the length of metal buried in the mortar between bricks or where mortar droppings adhered to portions of the nail. The presence or absence of insulation directly behind the brick made no difference in this corrosion pattern or severity.

In summary, very few wet wall problems were found in any field work away from coastal areas, in agreement with the broad thermography surveys. The spots of excessive moisture that are found, inland, appear to have little or nothing to do with condensation or the presence or type of insulation in the wall, retrofitted or otherwise.

The situation on the coasts is indeed different, again just as the thermography surveys have suggested. On the east coast, John McKenzie, P. Eng., has carried out the most extensive inspection on some hundreds of wet wall cases, both retrofitted and new stock; Scanada has hitherto been involved mainly with troubled new houses there. Essentially all of this complaint-case work has been carried out for private industry. Although not normalized or statistically assessable, the following points are indicative:

- In all inspections and surveys of new coastal houses (post 1975, not usually energy retrofitted) the vast majority of wet wall cases are electrically heated or otherwise relatively flueless. However, the majority of the new stock in the troubled neighbourhoods and regions are electrically heated; normalization is difficult to do. (VanPoorten[2] found that 80 to 90% of such new house complaint cases - with moisture problems of any kind - are electrically heated or otherwise relatively flueless. He was dealing with National Housing Act stock across Canada.)

- Of 59 inspected retrofit cases (McKenzie), 26 had no active flue although the great majority of the surrounding stock of similar age would have oil heating with active flues.

- 37 of the 59 had dirt floor basements, which may well act as abnormally strong moisture sources. (Other moisture sources or signs of excessive humidity were not assessed at the time.)

- About 20% of the retrofit cases and new house cases, on the east coast, had wall spaces wetted from window leaks in some spots, as well as from exfiltration-condensation in others. Horizontal slider windows were found to be the worst offenders. The window sills normally allowed excessive condensate to run down and enter the wall; rain entry was suspected in some cases. Almost all other spots appear to be resultants of exfiltration-condensation (McKenzie). In coastal British Columbia, it appears that such window rundown of water accounts for many of the wall spots (Cooper).

- On the east coast, the spots of excessive moisture (i.e. saturated or supersaturated wood or wood products) tend to be distributed on the lee side of the prevailing winter winds, and tend to be juxtaposed over indoor construction junctions (e.g. floor-into-wall or partition-wall junctions). McKenzie has prepared <u>Figures 3 and 4</u> from inspections of 80 cases, and Scanada has found essentially the same pattern in analysis of 230 thermographed cases in the same region.

SUMMARY OF FINDINGS ON INCIDENCE AND NATURE OF MOISTURE PROBLEMS

The field surveys and case work just discussed provide a considerable knowledge base on house moisture problems generally, not only on hidden condensation in the walls. In addition, the case studies underway for Energy, Mines and Resources Canada. as well as unpublished private industry projects, are filling in knowledge gaps concerning hidden moisture as well as the visible (surface) condensation which almost always precedes and accompanies it. The growing knowledge base can be summarized as follows:

- <u>Across Canada</u>, indoor surface moisture comprises the most common problem. Airtightness in newer construction or in retrofitted older stock, and/or flueless or relatively flueless heating, are usually associated with at least the more severe cases of excessive relative humidity in winter. Moderate or high occupancy loads are commonly involved as well, while below-grade moisture sources can be strong contributors. The indoor surface of window glass is the most common site of condensation resulting from this "indoor overload" set of conditions.

- <u>Atlantic coast, and especially Newfoundland</u>: The incidence of wet wall problem cases may approach that of, and follow from, the indoor overload problem. About 15% of newer houses and energy-retrofitted houses, if not others, appear to have significant patches of saturated wall sheathing near winter's end and into summer. The proportion of these that is flueless is not firmly known but is very high. Lack of active flues not only reduces air change rates and thereby increases relative humidity, but reduces the depressurization of the house and thus allows greater opportunity for condensation from exfiltration of indoor air. Such moisture accumulates firstly and most severely on the lee side of the house, downwind of the prevailing winter winds. At the same time, roof spaces with conventional attics generally appear to remain free of excessive or sustained condensation, perhaps because of "blow-through" ventilation from those same strong winds, coupled with frequent thaw periods even in midwinter. All of this may be thought of as the "horizontal flow" mechanism of moisture transfer, dominant in these coastal regions. Weak drying conditions in spring and early summer, abetted by entrapment by wrong sheathing papers and/or vapour-tight sheathing, also contribute to the retention of the wall moisture well into warm weather, inviting wood rot. The Swinton model discussed in this symposium allows assessment of these and other drying effects.

- Inland, and across the Prairies: The attic or roof space moisture problem may approach that of, and follow from, the indoor overload problem. The influence of lack of flues appears strong but again has not been quantified. Buoyancy action and sustained cold weather appear to be the dominant factors in exfiltration-condensation in inland Canada, where the climate is colder and the winds less strong and persistent than on the coasts. Inland, in brief, a "vertical flow" set of moisture transfer conditions appears dominant, in contrast to the coastal (or east coast at least) "horizontal flow" transfer conditions. In both cases, however, "indoor overload" is the common denominator of a moisture troubled house, as is discussed in the next section.

  Under inland conditions, the incidence of significantly wetted wall spaces may be only 3% or less; and perhaps half of the wet walls result from water rundown from wet roof spaces or window glass.

- British Columbia Coast: The wet wall incidence may jump to 12% or so in retrofitted stock, very much above the incidence inland but less than that on the Atlantic Coast. Roof space moisture may be common enough because of gross air leaks in certain wall-ceiling areas, and indeed the wet wall spots may generally prove to originate in roof condensation and/or window condensation.

- Across Canada, again: row houses are generally more prone to higher humidity and attendant moisture problems than single houses, and flueless houses are most prone. Water leaks through inadequate sill details (such as horizontal slider window sills) cause a lot of the wall troubles. Insulation does not appear by itself to delay drying or otherwise compound the moisture problem, but any retrofit which reduces air change, and thence raises humidity, raises the potential for condensation.

A WORKING CONCEPT: THE FEW PREREQUISITES FOR EXCESSIVE CONDENSATION

Most houses avoid moisture problems rather well; it takes a set of conditions, at least one or two being unusually severe, to develop and sustain excessive condensation on or in a particular component. Changing or avoiding just one or two of these conditions can correct or avoid the problem: that's the basis of guideline development.

Working with theory and with the growing field knowledge base, as just described in part, we have distilled a practical working concept of prerequisite condition sets and levels. Analysis of a sort has been involved, but the main defence of these field-derived ground rules is the fact that we find no strong exceptions in the field:

A. Indoor relative humidity above one critical level through much of the winter is the fundamental cause of excessive condensation anywhere in the house. The RH itself is a resultant of moisture generation rate and removal rate.

   For practical purposes, the critical RH level that causes excessive condensation on the coldest (sustained) indoor surfaces is about the same as that which can cause excessive condensation within the wall space or the roof space. The critical RH is defining itself as that level where the average dewpoint of the indoor air is at or above the indoor surface temperature of double glazing at the mean minimum daily outdoor temperature for the month of January, in a given region. That definition may be shifted a little as the studies progress, but it is clear that critical RH is an adequately assessable, predictable condition.

B. The critical level of Relative Humidity must be accompanied by certain other conditions to cause condensation problems within the envelope structure (i.e. outboard of the interior finish planes.

   These further conditions may be listed:

   a) gross leaks connecting the indoor air to the concealed spaces in the envelope and thence outward to planes well below the indoor air's dewpoint. ("Gross" refers to much bigger holes than those provided by normal construction shrinkage cracks, electrical outlet plates, or attic hatches. A gross leak into a wall space will at least allow a finger through; into an attic, at least a hand.)

b) retarded drying of concealed spaces due to impermeable exterior layers with inadequate bypasses, vents or drains to the outdoors

c) absence of an active flue and

d) inadequate moisture storage capacity in the outer layers.

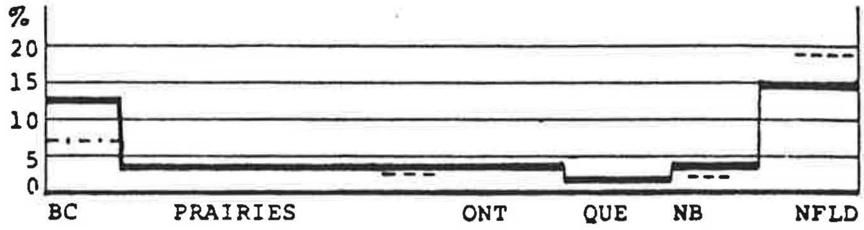
Wall spaces in coastal areas may be excessively wetted if the critical RH is accompanied by any two of the first three conditions a), b) and c). That is, gross leaks are not needed; ordinary construction cracks and penetrations can allow too much exfiltration in this "horizontal flow" regime.

Wall spaces in inland areas may be excessively wetted only if the critical RH is accompanied by all three of the conditions a), b), c) or perhaps if the critical RH is substantially exceeded and at least conditions a), b) and d) are present as well.

Roof spaces in coastal areas may be excessively wetted if the critical RH is accompanied by both a) and b), (the latter referring generally to inadequate venting, in the case of roof spaces).

Roof spaces in inland areas may be excessively wetted if the critical RH is accompanied by either a) or b), especially if an active flue is not present to help reduce the pressure driving indoor air into the roof spaces. Gross leaks are not needed; ordinary construction cracks can allow too much exfiltration in this "vertical flow" regime.

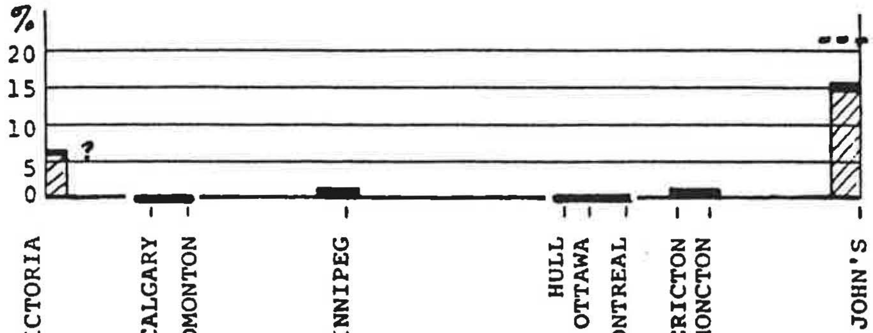
In summary, envelope wetting by condensation is mainly a matter of the wind-driven horizontal flow condition set on the coasts and the buoyancy-driven vertical flow set inland. Indoor surface condensation defines the RH level which can allow excessive condensation within the envelope. Clearly, retrofit actions which tend to raise the RH, increase the indoor air pressure, ignore gross leaks, and increase the potential for entrapment at planes well below the dewpoint of the indoor air, will all increase the likelihood and severity of moisture damage. This forms much of the basis for draft development of guidelines for moisture-wise retrofit, the subject of our second paper.



—— Directly probed walls in wall retro-insul. houses ——

---Thermographically scanned walls, all houses pre-'60---
(BC - 54 houses only - 1951-'60)

FIGURE 1 MEASURED AND APPARENT INCIDENCE OF WET WALL SPOTS IN OLDER HOUSES (PRE-1960) - % OF STOCK -



—— Thermographically scanned walls ——
(BC - same 54 houses as in Fig.1)

---post '75 flueless

FIGURE 2 APPARENT INCIDENCE OF WET WALL SPOTS IN NEWER HOUSES (1961-'82) - % OF STOCK -

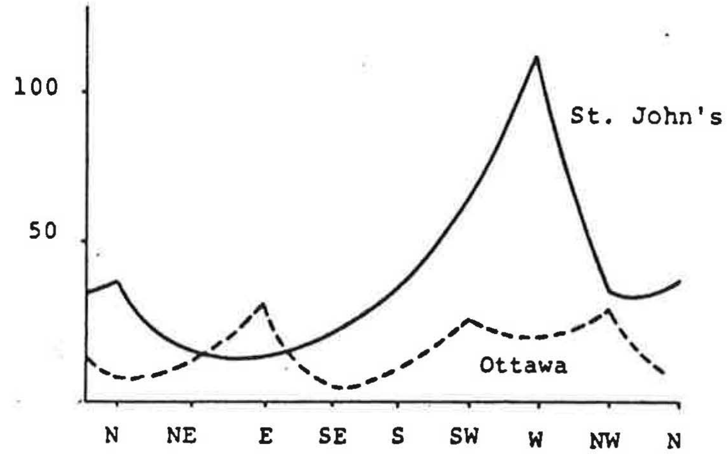


FIGURE 3 : WINTER WIND PRESSURE-TIME INDEX (V^2 x HRS)
(Dec. through Feb.)

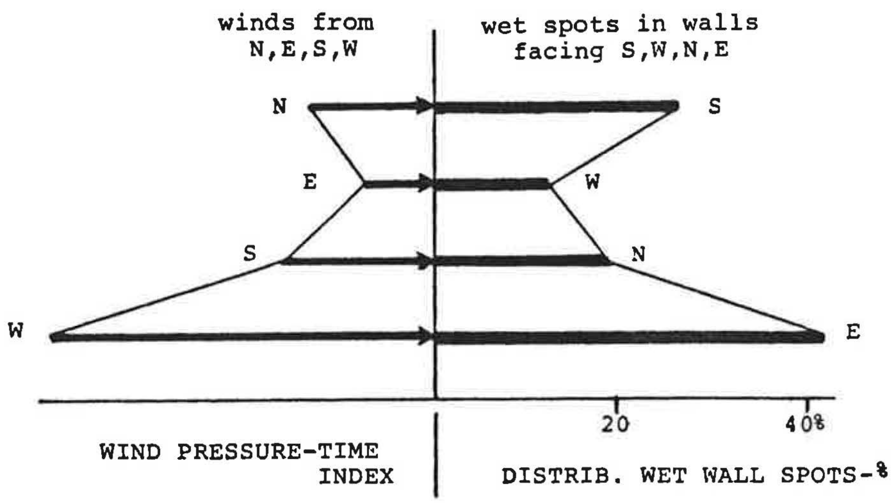


FIGURE 4 : DISTRIBUTION OF WET WALL SPOTS VS. WINTER
WIND PRESSURE TIME INDEX, ST. JOHN'S NFLD.

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