RESEARCH REPORT

Moisture in Canadian Wood-Frame House Construction: Problems, Research and Practice from 1975 to 1991

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MOISTURE IN CANADIAN WOOD-FRAME HOUSE CONSTRUCTION: PROBLEMS, RESEARCH AND PRACTICE FROM 1975 TO 1991

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Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act. This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part IX of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions. This publication is one of the many items of information published by CMHC with the assistance of federal funds.

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MOISTURE IN CANADIAN WOOD-FRAME CONSTRUCTION:

PROBLEMS, RESEARCH AND PRACTICE FROM 1975 TO 1991.

EXECUTIVE SUMMARY

Introduction

Canadian low-rise housing has evolved over a 100-year period using a wide range of timber-based construction products and building practices. This approach provided, for its time, essentially trouble-free housing. The evolutionary approach enhanced the "forgiving" nature of wood-framing and its ability to safely withstand repeated seasonal wetting and drying cycles.

During the period 1975 to 1991, significant advances were made in identifying, understanding and solving moisture problems in wood-frame houses. This progress was built on a substantial body of knowledge already existing. It was made possible because substantial funding for research, development and technology transfer was made available by various federal agencies.

This report collates and synthesizes the disparate research done by various agencies, including Canada Mortgage and Housing Corporation (CMHC), universities and the private sector and provides a consolidated picture of previous moisture-related performance improvements. A focus for future research into energy-efficient building product design and use has been developed, based in part on consultations with the international community.

Objective

- Compile and review documents produced over the past 15 years in relation to the study area and trace the role of Federal agencies in this area.

- Provide the perspective within which this federal effort was made possible, and identify the value of these achievements.

- Discuss the system behaviour of low rise residential housing and its overall effect on the moisture issue.

- Assess contributions the home building industry has made to the achievements identified.

- Discuss the benefits that the relevant demonstration and educational programs of both federal and private sectors have made on technology transfer.

- Identify current directions which the Canadian research community is now pursuing to achieve low energy, problem free, timber-frame housing.

Discussion

This report identifies how the moisture-related work was carried out through several public agencies, in concert with the house construction and retrofit industries. The study identified that, while each agency pursued its own mandate, the work was relatively well co-ordinated as a result of both formal and informal communication linkages. Formal mechanisms, to ensure this co-ordination, included various committees of the Inter-departmental Panel on Energy Research and Development (PERD) convened by Energy, Mines and Resources (EMR), and various steering committees for a number of major projects that involved other agencies and the industry. Ad hoc meetings of experts were also held, as when CMHC convened groups of building science experts to consider the evidence on moisture problems in the Atlantic region in 1981 and 1983. Joint participation in codes and standards committees, and in technical committees of the Canadian Home Builders' Association (CHBA), provided both formal and informal communication.

This report provides an assessment of the work identified. It has placed this work into a very broad, longer-term, historical perspective and, through use of an international forum, identified research issues which might now be further explored. Additionally, through the use of a number of appendices, the report identifies the work and the contribution of academic institutions, private sector researchers, industry consortiums, and building scientists at the Institute for Research in Construction of the National Research Council (IRC/NRC) and CMHC.

Findings

Prior to the 1970's energy crisis, little systematic research had been undertaken to better understand the systems aspects of moisture impacts on timber-frame housing. Subsequent increased airtightness (to reduce heat loss), and a move to more affluent lifestyles, increased internal moisture generation in a number of Canadian homes. These factors led to design and construction changes in timber-frame houses. However, many aspects of basic building sciences and traditional good-building practices were ignored. Significant advances were made between 1975 and 1991, in identifying, understanding, and solving moisture problems in wood-frame houses. The report emphasizes that this progress was built on a substantial body of knowledge already existing. The study found that more opportunities for formal communication and for identification of priorities and planning of research, involving the research community, would be advantageous.

Conclusions

Each agency pursued its own mandate but the work was relatively well co-ordinated as a result of formal and informal communication linkages.

CMHC and EMR ensured this co-ordination by creating steering committees for a number of their major projects, involving various government agencies and industry.

Joint participation in codes and standards committees, and in the technical committees of CHBA, provided both formal and informal communication.

In spite of the foregoing efforts, more opportunities for formal communication is required, and an identification should be made of priorities for any new moisture-related research.

PREFACE

Canadians have found, over the past 100 years, that wood frame systems provide an effective and affordable means of house construction. During the last 50 years a basement system has emerged which, when used with timber frame designs, increases overall usable space without diminishing affordability of Canadian housing. There is no lack of confidence in the structural durability of wood frame construction, however confirmed experiences do exist of moisture-induced problems in a small percentage of these houses. These experiences include warped sidings, collapsed flat roofs, moisture in basements and, rarely, some rotting framing. Research, as reported here, has contributed to the solution of these earlier problems.

With current moves to improved energy efficiencies in Canadian houses, achieved in part with relatively airtight envelope systems, additional concerns have been raised about the impacts of higher living-space relative humidities and local moisture condensation within wall systems. The inter-related and sometimes conflicting requirements of avoiding moisture problems, conserving energy, maintaining good internal air quality and minimizing housing costs, illustrate the complexity of these moisture problems. Fresh understandings have been developed in Canada and it is clear, from the development of these understandings as outlined in this document, just how difficult the task has been. The activities have ranged from basic scientific studies to investigations of construction practices.

Most Canadian house construction materials and components, because of their inherent low cost, have provided good value. However, due to the nature of many of these materials e.g. wood, wood-fiber, their performance thermally and hygrothermally varies over a wide range; for example, the vapour diffusion resistances of building papers and wafer board sheathing can vary over at least an order of magnitude. When these variabilities of properties in building materials are coupled with variabilities in workmanship, construction type, moisture and thermal loading due to occupancy, and with climatic variations from maritime, arctic and mid-continental conditions, the problems facing Canadian building scientists begin to come into focus.

This document identifies current areas of uncertainty and new work which could now be undertaken based on the Canadian knowledge-base developed to date.

The industry, evolving from the supply of wood and wood-based products to the home market, has already progressed into an exporter of Canadian goods and services. This exporting industry has the potential to expand. One of the hurdles facing this expansion is acceptance of timber frame construction in parts of the world where traditional masonry construction is known to be expensive but is seen as durable. The moisture summary provided here together with the knowledge of the reduction in use of "embodied" energy offered by timber-frame construction, should help those in other countries, with pressing housing needs, in their evaluation of options.

1. INTRODUCTION

This report is concerned primarily with activities related to moisture problems in Canadian wood-frame houses during the period from 1975 to 1991. These activities include the identification of moisture problems, research and development into causes and solutions, changes in materials and practice, and relevant changes in codes and standards. A substantial amount of research into moisture problems has been carried out and a number of changes in codes and practice have taken place during this period. Much of the research was implemented by CMHC. The objectives of the report are to review the issues that led to the research, the results of the research, the changes in materials, practice, codes, and the overall role of CMHC; and to identify current moisture-related issues.

Problems of building performance related to moisture have existed since shelters were first constructed. The nature and extent of the problems have been strongly dependent on climate, the details of the prevailing construction practice, and the indoor conditions. They generally involve degradation of materials in the building envelope, or degradation of the indoor air quality.

Buildings have traditionally been constructed to provide protection from the outdoor environment, including protection from precipitation. The building envelope is expected to tolerate exposure to moisture from this source. Buildings must also be designed and operated to account for the effects of water vapour contained in infiltrating outdoor air, and to avoid problems arising from condensation, within the building envelope, of water vapour contained in exfiltrating indoor air. Basements, crawl spaces and slabs on grade are expected to tolerate exposure to sub-surface moisture. Moisture problems in contemporary wood-frame construction arise from all of these sources.

Work of the principal national agencies involved with moisture-related research and development during the 1975-90 period, CMHC, EMR, NRC and Forintek, is reviewed in Appendix A to D. Work at the Centre for Building Science of the University of Toronto is covered in Appendix E. Work of certain other agencies is covered in Appendix F. The references on which the reviews are based are given in the bibliography (Appendix J). In addition, the views of a number of individuals, as listed in Appendix H, were sought. Changes to moisture related clauses in the National Building Code are reviewed in Appendix G.

Section 3 of the report begins with a summary of the energy conservation programs that had a significant impact on new house construction and on renovation practice throughout much of this period. The moisture issues of the time, and the results of research and development relative to house performance and building practice, are then summarized. This is followed by a summary of developments in new materials and equipment and of changes in codes and standards. Section 3 ends with a discussion of communication and interaction between the principal national agencies involved in moisture-related work.

The overall role of CMHC during this period is discussed in Section 4 of the report. Some current moisture issues are raised in Section 5 in relation to: science and technology, construction and retrofit practice, training and education needs, driving forces for change, and processes to encourage innovation.

In order to put this account into perspective, a review is provided in Section 2, of the evolution of wood-frame construction in Canada and the development, to 1975, of building science and practice in relation to the control of moisture in the building envelope.

2. BACKGROUND

Wood-frame construction has been the predominant building method in Canada for low-rise residential construction for the past 100 years [1] [2]. As first introduced into Canada from the USA, about 1870, it was known as balloon framing, with continuous 2 in. by 4 in. (25 mm x 51 mm) studs from foundation plates to roof plates. Exterior sheathing was of nominal 1 in. (25 mm) boards, 8 in. (200 mm) or wider, covered with one or more layers of building paper. Horizontal wood siding, shingles, stucco or brick were commonly used as the outside finish. Early versions often incorporated an inner sheathing of boards and building paper, which could be finished with plaster on wood lath. Later, plaster on wood lath was widely used with no other inner sheathing. Over the years, the balloon frame system was displaced by the platform frame system. This was distinguished by continuous studs between each storey, with a bottom wall plate supported on floor joists and a top plate supporting floor joists, and/or ceiling and roof frame work.

For many years it was uncommon to place anything in the space between studs, although saw dust, and even waste masonry material, was sometimes used to provide some insulating effect. By 1922 [3] the value of insulation materials in walls was being demonstrated in test huts at the University of Saskatchewan (similar huts were being used for the same purpose at the University of Trondheim in Norway). The materials available included saw dust and shavings used as fill. There were also a variety of batts and blankets made from a range of materials, such as straw, seaweed and mineral fibres, held between paper coverings. The use of insulation increased throughout the 1930's and problems arising from moisture accumulation in walls and attics during the heating season began to appear.

Rowley and colleagues at the University of Minnesota had been measuring thermal characteristics of building materials, including insulation, and began to study moisture movement and condensation in building envelope constructions under simulated winter conditions in the laboratory [4] [5]. They concluded that the primary mechanism of moisture movement in insulated wood frame walls during winter was diffusion of water vapour through the building materials [6], from the higher water vapour pressure indoors to that outdoors. Condensation occurred within the construction when the temperature at any plane through the construction fell below the dew point temperature of the atmosphere at the same plane. Condensation could be limited, or avoided, if materials with a high resistance to water vapour transfer (vapour barriers) were located on the warm side of the insulation, while materials with a low resistance were located on the cold side of the insulation. With pitched roofs, a low resistance to water vapour transfer, from the cold side of the insulation to the exterior, could be achieved by venting the roof space, preferably at both eave and peak levels.

In Canada, Babbitt [7] was measuring water vapour diffusion coefficients for building materials and developing similar concepts from diffusion theory. By the 1940's several research organizations in the USA were also measuring water vapour permeability and studying vapour transfer characteristics of building envelope components. These included the U.S. Forest Products Laboratory [8] and the Engineering Experiment Station of Pennsylvania State College [9] [10] (now University). The concept of diffusion as the primary mechanism for moisture transfer, leading to condensation of water vapour in building envelopes under winter conditions, was firmly entrenched. The use of vapour barriers for its control was widely accepted among building researchers and major building materials manufacturers. By the time of the post-war house building boom, beginning about 1946, insulation and some form of vapour barrier (often the supporting paper covering on batt-type insulation) were being widely used in new-wood frame construction, along with the venting of attics.

Canada Mortgage and Housing Corporation (CMHC) was founded in 1945, with responsibility for housing constructed under the National Housing Act. It established minimum house construction standards and a process for determining the acceptability of new materials and systems for use in NHA financed construction. The Division of Building Research (DBR) of the National Research Council (NRC) established in 1947, devoted substantial resources to providing technical support to CMHC, and in supporting the development of the National Building Code of Canada (NBCC).

CMHC Housing Standards of the period reflected the notions of condensation control that were then current. In 1950, two Canadian Government Standards Board (CGSB) Standards, 9-GP-2 and -3, were developed for building papers to be used as sheathing and vapour barrier membranes, respectively. The standards specified a maximum permeance of 0.75 perms for vapour barriers and a minimum permeance of 3 perms for sheathing papers. The latter were regarded at that time as having the function of minimizing air leakage into and through the wall due to wind action, and providing a second line of defense (after the cladding) against rain penetration. A number of building papers commonly used as sheathing membranes failed the minimum permeance requirement, so some manufacturers incorporated small perforations to overcome this problem. The perforations, in some instances, compromised the membrane's ability to pass a water penetration test.

Air infiltration and exfiltration through building envelopes had long been recognized as a significant component of heating load, and engineering methods to take it into account for purposes of sizing heating equipment were well established. One, the "crack method", which is still widely used, assumed that most of the leakage occurs through cracks associated with windows and doors. Estimates of air leakage were based on leakage data for these components for selected wind pressure conditions. It was also known that stack effect in high buildings could modify the pressure difference across the building envelope in winter and thus influence air leakage through the cracks. Winter humidities in commercial and institutional buildings were usually very low, however, and condensation within the uninsulated envelope was not regarded as a problem.

Hutcheon, in 1950, had noted the role of air exfiltration through a leaky ceiling as a major cause of winter-time water vapour condensation in the roof space of a building known as a Quonset hut. Nevertheless, his seminal paper in 1953 on design principles [11] does not identify air movement as a factor in water vapour transfer into the envelope. However, a number of pieces of evidence over the next few years led members of NRC's Division of Building Research (DBR) to the conclusion that air movement is the dominant factor in winter-time condensation occurring within the structure.

One of the key investigations, carried out in 1957/58 [12], was a study of factors influencing condensation between panes of non-sealed double windows. Measurements were made of air and water vapour flow characteristics of the air leakage paths around the tight-fitting inner sash. Calculations then showed that under typical winter temperature and humidity conditions, water vapour transfer by air movement was twice that by diffusion, even when the neutral pressure plane was at the mid-height of the window, i.e. under conditions where air exfiltration was occurring only through the upper half of the window, and where the maximum air pressure difference due to buoyancy forces over that height was only a fraction of a Pascal. With the neutral pressure level at the bottom of the window, the calculated vapour transfer by air leakage was ten times that by diffusion. Calculations based on similar measurements of air and vapour flow characteristics of $^1/_4$ in. (6.4 mm) diameter vent holes in the top and bottom of the sash, between the window air space and outdoors, showed that vapour flow by diffusion was insignificant relative to that due to air flow resulting from buoyancy forces acting over one-half the window height (i.e. at an air pressure difference of a fraction of a Pascal).

These results were a revelation to a researcher steeped in the diffusion dogma. The total equivalent leakage area of the inner glazing was less than one tenth of a square inch, spread over a 10-foot (3.05 m) window perimeter. This showed that the amount of moisture carried in exfiltrating air would overwhelm that due to diffusion, even with very small cracks and very small air pressure differences.

Other relevant evidence began to appear at the same time. Studies at the University of Illinois by Bahnfleth et. al [13] included measurements showing winter-time neutral pressure levels in two residences with fuel-fired furnaces. In the winter of 1958/59, observations of the effect of house buoyancy forces on chimney draft in a bungalow [14] indicated that the neutral pressure level was around ceiling height with the furnace on, and about two feet lower with the furnace off. This meant that attics, at least, were potentially vulnerable to significant moisture gains due to exfiltration through any gaps in the ceiling. While airtightness data for ceilings was not available, the existence of gaps around electrical boxes in ceilings, and around plumbing stacks, was well known. This vulnerability of attics is noted by Handegord in an early Canadian Building Digest (CBD) on vapour barriers [15]. An earlier study by Handegord [16] had identified the marked influence of heat transfer by convection in a stud space, when there were gaps in the insulation at top and bottom and an air space on either side. Joy, at Pennsylvania State University, subsequently noted the potential this also offered for moisture to bypass the vapour barrier.

During the period 1958-61, Wilson of NRC was Chairman of the ASHRAE Technical Committee on Infiltration and Ventilation, which was guiding a study of air leakage through entrance doors in high buildings [17]. The overwhelming influence of building stack effect was evident and Wilson revised the chapter on infiltration and ventilation in the 1961 edition of the ASHRAE Fundamentals Handbook accordingly. A section in a 1961 CBD [18] appears to be the first published unequivocal statement in North America on the importance of air leakage relative to condensation. It also introduces the notion of equivalent leakage area. A Scandinavian paper [19] on the effects of air leakage on moisture migration in wood frame construction, based on work in agricultural buildings, appeared the same year.

From 1961 onwards, field investigations by DBR/NRC [20] [21] uncovered increasing evidence on moisture problems in envelopes of multi-storey buildings. When NRC initiated the Building Science Seminar Series, first with in-house lectures to Public Works Canada in 1963, great emphasis was placed on control of air leakage to avoid moisture problems in high buildings. Increasing attention was also given to developing design solutions that dealt with the control of air leakage, as well as other fundamental concerns. The high air pressure differences across exterior walls of high buildings were confirmed by subsequent field studies [22] [23] [24].

Although building science practitioners are now well aware of the principles, moisture problems due to exfiltration continue to occur.

A number of changes in wood-frame residential construction occurred during the period 1955 to 1965. Interior cladding of plaster on gypsum lath was replaced by "drywall", generally $^1/_2$ inch (12 mm) paper-faced gypsum board. Use of tongue-and-groove or shiplap wood sheathing was largely replaced by use of panel-type sheathings of plywood and fiberboard. Waferboard sheathing was introduced during this period. In many regions use of wood-board sidings was largely replaced by use of aluminum and wood-composite sidings. Aluminum soffit panels were being used as an alternative to plywood. Wood trusses, generally of 2 x 4 (38 mm x 89 mm) members, largely replaced conventional 2 x 6 (38 mm x 140 mm) ceiling joists and roof rafters. Plywood largely replaced wood-board sub-flooring. Polyethylene film became available for use as an air-vapour barrier, and under-slab moisture barrier. Glass fibre insulation batts without paper facings("friction-fit") were introduced.

Serious moisture problems due to condensation in wood frame residential construction as built in the 1955-1965 decade, did not appear to occur frequently (at least in southern parts of Canada). An exception (the cause of frequent complaints) was excessive condensation on indoor surfaces of windows, particularly on metal sash and frames, and on the inside surface of outer panes of openable double windows.

In the early 1960's, DBR/NRC carried out extensive laboratory tests on indoor surface temperature characteristics of various window frame and sash arrangements in support of the CMHC materials acceptance program. Convection in the air space, as well as frame and sash design, were recognized as significant factors [25] [26] [27]. In reference 26, the notion of the temperature index for defining one aspect of thermal performance was introduced. The results led to the inclusion of a surface temperature performance requirement in the CGSB standards for windows, then being formulated. Work on window performance, including the study of factors influencing condensation, was continued by Sasaki [28].

During this same period DBR/NRC carried out tests on air leakage characteristics of various production windows [29] [30], which led to performance requirements in the CGSB window standards, and to a general increase in window airtightness. The test method developed in Canada became the basis of the ASTM procedure now widely used. To assist in the control of condensation between panes of double windows, the CGSB standards required that the airtightness requirements be met by the inner sash alone. Fundamental considerations showed that, with normal residential indoor humidities, venting the air space to outside is effective in controlling condensation between panes of double windows when the inner sash is very tight and the indoor to outdoor air pressure difference is small [29] [31].

Elimination of condensation on the inside of the outside pane of glass was one of the advantages offered by factory-sealed double glazing. Until the late 1950's this product was produced by only two of the major glass manufacturing companies, with rigorous in-house quality control. New sealant materials became widely available at that time, and this encouraged a large number of small companies to enter the market. Achieving, in production, a hermetic seal with sufficient durability to perform satisfactorily for even 5 years (which was then the normal guaranty period), was not easy. Large numbers of failures came to the attention of CMHC, mostly involving condensation between panes and "scumming" of the glass surface from alkali in the glass. A research program led to the development of test methods to predict probable performance [32] [33], and to the development of a CGSB standard (now CAN 2-12.8). Water vapour transfer in this case was recognized as resulting primarily from air leakage through very small passages, due to the pumping action induced by temperature and barometric pressure changes.

Hermetic seal failures were greatly reduced as a result of qualification testing required by CMHC. The generally high conductance of the edge spacer detail resulted however, in lower indoor edge temperatures than with non-sealed double glazing arrangements in wood sash [34]. The design of thermally-improved edge details is currently receiving considerable attention.

As noted above, condensation problems in the envelopes of wood-frame residential construction were relatively infrequent in southern Canada during the 1960's. This was, in part, due to the generally moderate indoor relative humidities in winter that prevailed [35]. These levels were a reflection of the fairly high natural ventilation rates, resulting partly from the presence of vented heating appliances [36]. With the furnace operating, ventilation rates of 3 air changes per hour (ach), or more, were possible under average winter conditions. The effect of the furnace operation on neutral pressure plane levels, noted earlier [14], was confirmed [36]. Envelope airtightness data for houses were not available then, but in 1964 fan depressurization tests were carried out on the two houses that were the subject of reference 36. The results, which included data for four other houses, were not published for over a decade [37]. They showed, among other things, a relatively high equivalent leakage area (ELA) for the ceiling construction of four of the houses, ranging from about 0.02 m^2 to 0.045 m^2.

Wood-frame residential construction, which generally performed adequately in southern Canada, had a much higher incidence of moisture problems under the severe winter conditions in northern Canada. Ventilated roof spaces were particularly vulnerable [38]. It was known that the problem was associated with excessive air exfiltration and the limitations of roof space ventilation as a mechanism for moisture removal under low temperature conditions. Field measurements in Ottawa residences, carried out by DBR/NRC in 1950 and unfortunately never reported, had shown large day-time increases in attic air temperature as a result of solar heating, even with low outdoor temperatures. This increased the moisture removal effectiveness of attic ventilation. Conditions of periodic solar heating, and outdoor temperatures above freezing, did not occur as frequently in the latitudes north of 60, and the development of airtight construction practices was not yet advanced.

Electric heating was being promoted by Ontario Hydro and other provincial electric power utilities in this period. Electric heating was accompanied by higher insulation R-values than was normal at the time for houses heated with other fuels. By the late 1960's condensation problems, primarily condensation on window surfaces and in attics, were being reported in some electrically heated residences. An Ontario Hydro study [39] established that there was a tendency for tighter houses to have higher humidities, and for attic condensation to coincide with high indoor humidities. This was the first extensive use of airtightness testing by fan depressurization. Equivalent leakage areas (ELA's) for the 20 electric-heated houses ranged from 0.10 to 0.36 m^2, which would be regarded as moderately to very leaky by today's standards. Indoor relative humidity (at 21°C in March) ranged from about 46% to 26% for the lowest and highest ELA values respectively.

It was recognized that, in general, condensation problems were associated with lower ventilation rates and greater exfiltration air pressure differences across the ceilings of houses without vented heating equipment. Much more severe condensation was observed in attics of electrically-heated houses in a northern community [40]. It was concluded that it is necessary to exercise great care to achieve an airtight construction for such conditions.

In the early 1970's, problems of excessive condensation were reported in flat wood-frame roofs, which generally had eave vents leading to the air space above the insulation. Most of these were electrically-heated row houses. Field studies in the Ottawa area by DBR/NRC [41] indicated that condensation often occurred in joist spaces in which air flow was restricted and opportunities existed for air leakage from indoors, e.g. at the intersection of partition walls and ceilings. Air pressure measurements confirmed the potential for exfiltration into the joist spaces. Pressurizing the space above the insulation by mechanical ventilation (with outdoor air) was shown to be effective in reversing the direction of flow. It was concluded that, for new construction, the most effective approach was to increase the airtightness of the ceiling construction.

Similar problems occurred in electrically-heated row houses in Montreal and, as a result, CMHC issued a Builder's Bulletin on construction practice for flat and cathedral roofs. Subsequently, the 1977 NBCC called for special requirements for roofs with low slopes (or no attics), when insulation is placed below the roof sheathing. These called for application of cross purlins on top of the joists, and provision of a uniformly distributed vent area, not less than 1/150 of the ceiling area, to improve roof space ventilation. General requirements for vapour barriers required that they extend over the top of interior walls to form continuous vapour protection, with the clearances around chimneys and vents sealed. For low-slope roofs, joints in the vapour barrier (overlapping) were to be made only over framing or blocking, with the holes around service penetrations sealed.

The 1977 NBCC also required a mechanical exhaust system with a capacity of at least 100 cubic feet per minute (cfm) (47 l/s) when there was no fuel-fired heating equipment within the dwelling unit. This was withdrawn in the 1985 NBCC when ventilation systems were required in all dwelling units. The special requirements for low-sloped roofs are generally the same in the 1990 NBCC.

During the 1960's and 1970's, DBR/NRC also gave much attention to the problems of failures of waterproof membranes and wetting of insulation on structural decks of flat roofs, and to developing good practice recommendations [42] [43]. The literature is extensive, but will not be reviewed here, as roofs of this type are not widely used in wood-frame residential construction.

During this period there was much emphasis at DBR/NRC in defining and disseminating fundamental principles of building envelope design as an integrated package. This included control of both condensation and rain penetration. The "open rainscreen" approach to the latter, based largely on principles developed by Norwegian researchers, was promoted as a preferred alternative to face-sealed joints [44] [45]. It required attention to airtightness and the distribution of air pressures within the wall, as did control of air exfiltration. Much of this attention was on application of the principles to the design and construction of multi-storey buildings.

Drainage of any water penetrating joints in the exterior wall from outdoors has long been a feature in design. The concept was advanced that walls be designed to allow condensate, which might accumulate as ice, to be removed by drainage when it melted [46]. The concept of storage of condensed moisture, at acceptable levels, in outer wall components during cold weather periods, to be dissipated during more favourable weather, has been a component of moisture control theory for many years. Protocols for laboratory evaluation of condensation control in wood frame walls at Pennsylvania State College in the late 1940's, on behalf of the U.S. Housing and Home Finance Agency, incorporated a limit on moisture content increase for wood sheathing. Platts attributed the successful moisture performance of insulated plywood panel construction in the far north to the absence of air leakage, to the capacity to store moisture (transferred from indoors by diffusion during the winter) at acceptable levels in the outer skin, and to the escape of this moisture by diffusion during the summer [47]. Seasonal storage of moisture, transferred from the indoors by diffusion, has also been a consideration in moisture control concepts for roof design [48] [49].

Seminars and practice documents during the 1960's and 1970's dealt extensively with the importance of airtightness for condensation control. The concept of an air barrier, as distinct from a vapour barrier, was used. The importance of the continuity of the air barrier, and the need for it to be able to withstand wind loads, was stressed, along with the lesser importance of continuity in the vapour barrier.

A document by Latta [50] in 1973 summarizes the theory and design concepts being put forward at that time. An air barrier to stop air movement was identified as the primary requirement for the control of condensation in winter. Placement of the air barrier in contact with the insulation was regarded as essential. The purpose of this was to ensure that air spaces do not occur on both sides of the insulation, which would allow the transfer of air by convection (and therefore moisture and heat) through the insulation [51]. Placing the air barrier on the warm side of the insulation, rather than on the cold side, was recommended in order to minimize stresses on it due to temperature change and to avoid the possibility of condensation on a cold air barrier. Diffusion was identified as only of secondary importance (although not to be ignored) as a mechanism of moisture transfer in relation to condensation control. An analysis of steady state vapour pressure gradients and flow, to and from potential condensation planes under winter design conditions, based on diffusion theory, was recommended as a basis for determining the potential for drying of components that might become wetted.

Building Science Status in 1975

By 1975, the primary importance of air exfiltration in relation to condensation in building envelopes was well established in building science. The influence of stack effect was well known, and the greater susceptibility of attics and upper wall areas to condensation problems was recognized. Venting of roof spaces and unheated crawl spaces was a long established practice. It was known, however, that traditional ceiling and attic construction did not perform adequately in the far north, and that a more effective air barrier was required.

The principles for rain penetration control were well established, including requirements for both face-sealed and rain screen systems. Joint technology was quite well advanced. Practice, however, often failed to meet the principles. Joint and flashing details in wood-frame construction were often inadequately executed.

The requirement to control air leakage, as well as vapour diffusion, had appeared in Part 4, Design, of the NBC since 1965. Part 9, Housing and Small Buildings, had not yet made explicit reference to the control of air leakage, but it did call for the vapour barrier to protect the entire wall area, including framing membranes, and for it to be continuous where interior partitions intersect ceilings and exterior walls. Both Part 4 and Part 9 recognized a potential problem when materials having a high resistance to water vapour transfer were used on the exterior side of the major thermal resistance. Part 4 required a vented air space (or other effective method) to remove the water vapour. Part 9 called for Type 1 vapour barrier with a higher resistance to water vapour transmission by diffusion. In retrospect, this would have resulted in little reduction in winter-time moisture accumulation because moisture transfer was caused mainly by air exfiltration.

By 1977, Part 9 called for weather-stripping of attic hatches, and sealing of clearances around chimneys and vents at the entry to attic and roof spaces. Openings for other services were to be cut so that the vapour barrier fitted snugly. There were also special air sealing and roof-space venting requirements for low slope and cathedral roofs. The increased probability of higher relative humidities and condensation problems in electrically heated houses was known. Part 9, accordingly, called for the installation of mechanical exhausts in houses not heated by fuel-fired equipment.

Dampproofing requirements for basements had not changed for a number of years. The typical exterior dampproofing of basement walls, with asphalt emulsions or cut-backs, probably did little more than color this outer surface black. Interior dampproofing of 2-mil poly, or two coats of bitumen, required when interior cladding was to be applied, was probably more effective. Basement slabs had either to be supported on granular fill, or dampproofed with 6-mil polyethylene or 45 lb. roll roofing on the underside.

3. EVOLUTION OF PERCEIVED MOISTURE ISSUES 1975 - 1990

3.1 Impact of Energy Conservation Programs

The single most significant factor influencing building research, technology and practice for more than a decade, beginning in 1975, was the energy crisis. This resulted from increased oil prices initiated by the OPEC cartel in 1974. In the government programs that followed, aimed at security of supply and self-sufficiency, energy used for buildings (both existing and new) was a primary target for conservation. Conversion from the use of oil to other energy sources was also a priority.

At the federal government level Energy, Mines and Resources Canada (EMR) was given the primary mandate to implement the energy policy. New branches were established and new programs with major budgets were initiated. The principal ones concerned with residential buildings are summarized in Appendix B. Energy programs were given one of the highest priorities by the government and all government agencies were expected to respond accordingly, under overall EMR direction. Staff at EMR were recruited for their initiative and their commitment to achieving energy objectives. They were given substantial responsibility and authority. For the most part they did not have extensive experience in building science and practice. They were generally results-oriented and prepared to take risks to achieve objectives.

The National Research Council was given a primary responsibility for implementing energy R and D, and were allocated funds dedicated for this purpose. It established a new division of Energy to manage the program, most of which was contracted out to universities, provincial research organizations, industry and private consultants. Some research was carried out by transfer of funds to NRC operating divisions. The Division of Building Research, for example, carried out major energy projects, including technical support for the preparation of the Measures for Energy Conservation in New Buildings (under the Associate Committee on the National Building Code). Some new staff were recruited, but a number of experienced regular staff members were heavily engaged in this energy work.

The Canadian Home Insulation Program (CHIP) was delivered by CMHC, from 1981, through contractual agreements with EMR. EMR retained responsibility for implementing related research, standards and technology transfer. EMR also initiated the R-2000 Program (initially known as the Super Energy Efficient Home Program) and retained responsibility for its implementation, including related R and D, standards and technology transfer.

CMHC did not have a major role in the national energy program. It continued to be responsible for assessing the acceptability of materials under the NHA, and for the general adequacy of NHA financed housing. It began to build up an in-house research capability, including building science, and to contract out research, with less reliance on DBR/NRC.

Urea formaldehyde foam insulation (UFFI) was one of the products accepted for use in the CHIP program. Reports of apparent adverse affects on the health of residents of UFFI-insulated homes led Health and Welfare Canada to take the decision to ban the use of UFFI. Consumer and Corporate Affairs (CCA) added UFFI to its list of hazardous products in order to make the ban effective. Extensive research on the problem was initiated by CCA, mainly through NRC. It was claimed that the market value of houses that had been insulated with UFFI had been reduced because of the adverse publicity. Court action to obtain compensation was initiated by home owners.

CMHC was in an unenviable position, with its dual responsibility for the CHIP program and the building products acceptance program. There is a view that this experience was a factor in accelerating the decision to transfer the management of new product assessment to NRC (CCMC), and in the build up of an in-house research capability. There is also a perception that CMHC technical staff had a somewhat negative approach to some of the energy conservation programs initiated by EMR, concentrating on potential problems. This included moisture and indoor air quality issues. Some of the concerns, particularly in regard to energy retro-fitting, appear to have been justified.

3.2 Early Moisture Issues

By the early 1980's, a number of concerns were being raised about the potential for moisture problems resulting from implementation of energy conservation measures in residential construction. These included:

- reduction in flue action resulting from the use of high efficiency furnaces, or its elimination by the use of electric resistance heating, causing a reduction in the rate of natural ventilation and, therefore, leading to a higher indoor humidity,

- reduction or elimination of effective flue area resulting in a lower neutral pressure level and, therefore, a higher potential for air exfiltration through ceilings and upper wall areas,

- air sealing, and increased insulation, reducing overall air leakage and, therefore, causing increases in indoor humidity,

- increased airtightness increasing the probability of spillage of combustion gases from vented fuel-fired appliances. This presents a potential health hazard and a potential source of increased indoor humidity,

- night-time reduction of indoor air temperature increasing the probability and extent of condensation on interior surfaces,

- increased condensation on interior surfaces increases the potential for mould growth and related health problems,

- while air sealing reduces overall air exfiltration, some points of leakage may not be eliminated. The potential for interstitial condensation is higher at these locations because of the higher indoor humidity,

- increased cavity insulation reduces the temperature of the outer envelope components and, therefore, increases the potential for condensation, and

- some insulation practices, e.g. use of low permeability insulation sheathing, reduce the potential for drying of moisture in wall framing.

While there was little argument that energy conservation measures would tend to increase the probability of certain moisture problems, there were questions about the extent and nature of the increase, and what needed to be done to minimize the risk. The CMHC cross-Canada survey (Reference 5, Appendix A) provided some evidence on the extent of moisture problems (whether or not due to energy conservation measures) and became a point of departure for subsequent studies.

3.3 Summary of Results of Research, 1975 - 1990

A large amount of research and development was carried out, in Canada, during the period 1975 - 1990. Much of it is summarized, or referenced, in Appendices A, B, C, D, E and F. Some additional research was carried out by the building industry, provincial agencies, and universities. The following is an attempt to summarize the results as they relate to building practice.

- It was confirmed that houses without flues are likely to have higher indoor humidities in winter and are more likely to experience moisture problems than those with flues, other conditions being similar.
- With the exception of the Atlantic Region, and to some extent coastal B.C., the frequency of serious moisture problems in traditional wood-frame houses in southern Canada is relatively low.
- Moisture problems arising from indoor moisture sources are usually coincident with high indoor relative humidity.
- Mould and mildew on interior surfaces of building envelopes is not uncommon with high indoor humidity, particularly in locations where heating is relatively ineffective or thermal resistance of the envelope is low. Periodic reduction in indoor temperature can exacerbate the problem.
- Serious winter-time moisture problems in traditional houses in southern Canada, arising from indoor moisture sources, can generally be avoided by maintaining indoor humidity at reasonable levels, as indicated by the extent of condensation on double windows, and sealing major air leakage paths from indoors into wall and roof spaces.

- Excessive indoor humidity in winter can be avoided by controlling obvious indoor moisture sources and by providing the necessary rates of outdoor air supply. In tight houses, mechanical ventilation will usually be required. The rates of ventilation required for humidity control will usually be less than those required for other aspects of indoor air quality, when appropriate attention is given to the control of indoor moisture sources.

- While passive vent stacks can significantly increase rates of natural ventilation in winter, the practicality of their widespread application for humidity control is questionable. Exhaust rates through such stacks can vary widely with changing outdoor air temperature and wind. Noise is also an occasional problem.

- Basements can be a significant moisture source in winter; sources are transfer of soil moisture through walls and floor slabs under some conditions, and soil gas entry through joints and cracks. The rates of basement moisture generation are difficult to quantify and have not been well established but are already known to vary widely.

- The moisture source strengths in houses in winter can be quite variable. The contribution of spring-to-fall moisture storage indoors to winter-time moisture supply has not been quantified.

- The potential for dissipation of moisture (drying) in building components, during the spring-to-fall period, is significantly less in some parts of the Atlantic provinces than in other parts of southern Canada, with the possible exception of coastal B.C.

- The moisture content of construction framing in Atlantic Canada is likely to be above the recognized limit of 19%, and may be above the fibre saturation limit.

- The moisture content of framing used in other parts of Canada is generally, although not always, at or below 19%.

- The moisture content of initially wet framing in finished walls is likely to remain above desirable levels for extended periods in Atlantic Canada, and may result in some moisture damage, depending upon the properties of the sheathing and cladding components. In other parts of southern Canada, with the possible exception of Coastal B.C., initially wet framing lumber is likely to dry to acceptable levels in a short period, depending on the wall construction. The use of wet framing lumber leads to drywall "nail popping" and reduction in airtightness of exterior nails. The latter increases the possibility of moisture problems due to air exfiltration.

- Low vapour permeability sheathing and cladding arrangements reduce the rate of dissipation of moisture in framing materials. With these arrangements it is prudent to minimize the amount of moisture to be stored in winter months, particularly in locations where the spring-to-fall drying potential is poor, e.g. Atlantic and northern Canada.

- Application of cladding over furring strips may increase, appreciably, the rate of drying of wet wall framing in Atlantic Canada when sheathings with a low resistance to vapour transfer are used, but does not have a significant effect on the rate of drying when sheathings having a high resistance are used, at least when the furring air spaces are blocked at the top and relatively airtight siding is used.

- Insulating sheathings can be effective in reducing winter-time condensation in insulated wall spaces when their use significantly reduces the accumulated time over the winter during which the inner surface temperature of the sheathing is below the indoor dew point temperature.

- Insulated wood-frame walls appear to be capable of handling relatively large amounts of moisture in air flowing from indoors to outdoors in temperate Canadian winters if there is appropriate provision for storage of condensate during below freezing periods and drainage during periods of melting.

- Air interchange between cavities of wood-frame walls and the indoor environment, due to pumping action induced by fluctuations in wind speed or in outdoor temperature, is likely to be small in comparison with air flows due to buoyancy forces between the cavity and indoors, or air flows due to indoor-outdoor pressure differences caused by wind and building stack action. Such pumping action is therefore not likely to contribute significantly to winter-time condensation in these walls.

- Wood-based sidings need to incorporate features to minimize their sensitivity to moisture and to utilize application details that minimize wetting from both interior and external moisture sources. The Atlantic Canada climate presents a particularly severe service environment for moisture-sensitive sidings.

- It was confirmed that repetitive paint failure on wood siding, as typically installed and finished, is relatively common in the Atlantic region.

- Problems with moisture of outdoor origin often occur in the Atlantic region, as a result of poor detailing and poor installation of siding systems and flashings.

- Severe attic condensation problems are not extensive in southern Canada, and occur primarily in houses with excessive indoor humidity and without flues.

- Traditional roof construction with ventilated roof space does not provide adequate moisture performance in the Canadian north because of: the difficulties of achieving adequate airtightness; the problem of blowing snow; the long winter during which condensation can occur; and the relatively low spring-to-fall drying potential. A well sealed cathedral-type roof construction, without ventilated air space, generally provides acceptable performance.

- If concrete basement walls are to be insulated and finished on the interior within a few months of basement construction, special provision is required for dealing with construction moisture in the concrete and for preventing moisture transfer from indoors to the inner concrete surface.

- Some systems for insulating the exterior of basement walls provide a number of proven advantages for moisture control.

- Glass fiber insulation for below-grade exterior applications has advantageous fiber orientation and size distribution characteristics which limit the penetration of soil moisture, provide effective drainage, and limit moisture content so that thermal resistance is not significantly reduced.

- Thought must be given to the moisture and durability consequences when insulating existing basement foundation walls on the indoor side, particularly those of clay brick or stone. Potential damage due to the movement and concentration of salts in the foundation materials is of special concern.

- Reports of structural damage due to adfreezing of soil to walls of heated basements with interior insulation have not been verified. Theory indicates that such damage is unlikely to occur with most such walls; concrete block walls with interconnecting air spaces may be an exception.

- Super energy efficient envelopes, meeting R-2000 airtightness standards (maximum of 1 $^1/_2$ ach at 50 Pa, or normalized ELA not more than 0.7 cm^2/m^2), as constructed in southern Canada, appear to be free of winter-time moisture problems due to indoor sources when mechanical ventilation, at levels required for indoor air quality, is provided.

- It is practical to achieve house airtightness levels corresponding to 1-$^1/_2$ ach at 50 Pa with carefully sealed polyethylene air-vapour barriers, or with carefully implemented airtight drywall methods. An exterior wall wrap of spun-bonded polyolefin (SBPO) membrane, or equivalent, potentially offers another approach to achieving the required level of wall airtightness, assuming that air interchange between wall spaces and indoors is appropriately restricted.

- The service life of polyethylene membrane may be unacceptably short if it is not properly formulated with virgin resin.

- A reasonably effective resistance to air leakage is required in the outer layers of wood frame walls, to protect the cavity insulation from local air leakage due to wind action. While this was one of the functions of traditional building paper, typical methods of application generally have not achieved the desired results. A wrap of SBPO membrane, with joints taped and adequately supported to withstand wind loads, has been shown to be effective.

- The airtightness of tract-built project houses in Winnipeg is approaching that required by R-2000 standards. Average house leakage values in other parts of the country are two times higher, more or less, except for Vancouver with values that are about four times higher. Average air leakage values of houses across Canada have been reduced by about 30% from 1982 to 1989.

- Naturally aspirated fuel-fired vented appliances will spill flue gases when the house is depressurized (with respect to outside) by about 5 Pa during mild winter weather. This level of depressurization is likely to occur in reasonably tight houses with activation of typical exhaust devices. Thus it is prudent to use fuel-fired devices that have higher depressurization limits (e.g. 20 Pa), or to provide make-up air for exhaust devices so that depressurization is maintained within the tolerance of the venting systems.

- The materials properties, driving forces and transport mechanisms affecting moisture content in wood frame walls as a function of time are very complex, and accurately predicting the moisture content changes in the components of complete walls throughout the annual weather cycle is quite difficult. The extent to which models currently under development can provide useful results has yet to be established.

- The potential of the dynamic wall concept for energy savings associated with both ventilation air and with incident solar radiation has been demonstrated, at least for weather conditions in southern Ontario. The development of systems to take advantage of this potential, that can be economically and effectively applied by the building industry, remains a challenge.

3.4 Changes in Materials and Practice, 1975 to 1991

The Saskatchewan Conservation House demonstrated that relatively tight enclosures could be achieved with careful application of continuous polyethylene film, with special attention to sealing of overlaps and penetrations. This approach was widely used with success in the R-2000 Program. The "airtight drywall" approach to providing air barrier protection was developed subsequently, and was also shown to provide the level of airtightness required by R-2000 standards (protection against vapour diffusion is provided by other components). In utilizing these approaches there has been substantial reliance on the use of caulks, sealants and gaskets. A variety of caulks, sealants, and weather-stripping products are also used for air sealing of existing houses. Polyethylene "pans" are now commonly used to enclose electrical boxes in outside walls in order to provide continuity in the air barrier protection.

There has been increased use of spun bonded polyolefin products as weather wraps on the exterior of sheathing materials. These provide protection against wind-induced air leakage through stud-space insulation, and may be suitable as the primary wall air barrier if adequately supported to withstand wind loads. As noted in Appendix A, envelope tightness has been generally increasing over the past decade, and the trend is likely to continue with more explicit requirements for the provision of airtightness in the 1990 NBCC. There has also been a substantial increase in insulation levels. R-20 (RSI 3.5) wall insulation, with 2 x 6 in. (38 mm x 140 mm) studs, is now widely used. R-40 (RSI 7) roof insulation is also common. There is also greater use of insulating sheathing materials of glass fibre (covered with SBPO) and foamed extruded or expanded polystyrene.

High efficiency fuel-burning furnaces are used increasingly. These generally have improved venting systems which can tolerate greater levels of house depressurization than naturally-aspirating furnaces.

The R-2000 Program called for installation of mechanical ventilation systems and its energy performance standards favored the use of heat recovery ventilators. With the requirement for the provision of mechanical ventilation systems in all houses in both the 1985 and 1990 NBCC, and the development of CSA Standard F326 on residential mechanical ventilation systems, there has been a considerable advance in ventilation technology for residential construction.

A number of improvements have been introduced in basement construction practice. Many of these are reflected in the 1990 NBCC. A granular layer and 6-mil polyethylene membrane are required under floor slabs. The slab is to be sealed around the perimeter of the adjacent wall with flexible sealant, and all penetrations of the slab are to be sealed, in order to prevent water vapour and soil gas leakage. Floor drains are to have a method of ensuring that the entry of water vapour and soil gas into the house is prevented.

Insulation products suitable for use on the exterior side of the basement wall are being used increasingly. Some of these provide for gravity drainage of soil water to the footing drains. There is also a patented fluted moisture barrier for this purpose. Further improvements to basement dampproofing, airtightness and insulating practices are anticipated as a result of current studies, and the industry's interest in improving this aspect of house performance (to avoid warranty claims that are commonly encountered with leaky basements) is growing. Systems for venting radon, soil gas and water vapour, which would otherwise enter basements through cracks and openings in walls and floor slab, offer potential for venting moisture evaporating from finished, insulated, basement walls of new houses.

Some notable improvements have been made in construction practices for northern housing. Air sealing practices have been improved. The use of weather wraps of SBPO membrane or equivalent is now common. Roof space condensation and snow entry have been largely overcome by the use of fully insulated cathedral-type ceilings (no attics) with effective air/vapour barriers and with no exterior vents.

3.5 Documentation and Technology Transfer, 1975 to 1991

Documentation of developments in science and technology, and the transfer of scientific and technical information, can involve a range of targets and can take different forms. At the primary level it involves the production of scientific and technical reports and papers. These are generally directed toward a sponsor or a peer group. The process of presenting and defending scientific and technical papers before a peer group is another form of technical information transfer. Many of the documents referenced in Appendix A, B, C, D, E and F are in this category. Some are client reports, and are not documents offered to the public or made available in public technical libraries. They have, however, been available on request to building science practitioners.

In the case of many of the CMHC and EMR projects, an advisory committee was established to review progress and results. This provided another vehicle for technology transfer. In some instances special meetings of building science specialists were held to exchange ideas on research priorities (see Appendixes A, D and I). Meetings of committees under the Program for Energy Research and Development, held for similar purposes, provided another vehicle for communication.

Codes and standards represent another type of technical document that has a technology transfer function, as well as regulatory and standardization functions. The changes in the provision of the NBCC respecting moisture have been reviewed in Appendix G, and summarized in Section 3.6 The NBCC, and corresponding provincial building codes, have had a major role in influencing building practice and in transferring technology to the practitioners, including builders, manufacturers, designers and building officials.

The emphasis in codes is on what to do, rather than on why and how. A commentary in the NBCC, incorporated as an Appendix, begins to address why and how. Standards perform a similar technology transfer function. They inform the manufacturer, testing agency, specifier and installer. The commentary now incorporated in some standards (e.g. CSA F326) provides information on the rationale for the various provisions in the document. The process of developing codes and standards is also a vehicle for transfer of information among those involved.

Building codes are intended to be a set of minimum provisions for the health and safety of building occupants. Part 9 of the NBCC, nevertheless, has generally been taken by house builders as representing acceptable practice. As noted, codes generally do not explain, in detail, how to build. CMHC has produced a number of documents intended specifically for education and training purposes, addressed to builders. On the issue of housing moisture problems, CMHC, in association with the Canadian Home Builders Association (CHBA) has published:

- Construction Principles to Inhibit Moisture Accumulation in Walls of New Wood Frame Housing in Atlantic Canada
- Moisture Problems

The former was largely the result of the work of the joint CMHC/CHBA Task Force on Moisture Problems in Atlantic Canada, which itself was a notable example of information exchange on building practice. The latter document deals with a range of moisture problems and solutions, and was one of the documents used for instructional purposes in a series of builders workshops delivered through CHBA. CMHC documents and workshops have promoted a systems approach in the design and operation of houses.

As noted in Appendix B, EMR has produced a range of practice documents for the R-2000 Program, and has offered courses to builders through CHBA. EMR also produced good-practice documents on Insulation and on Air Leakage Control for the retrofit industry, and has offered courses through the National Energy

Contractors Association (NECA). It also supported the development of a design and installation manual for ventilation systems, and offered courses through the Heating, Refrigerating and Air Conditioning Institute (HRAI). The EMR-sponsored training courses emphasized the interaction of the house envelope, mechanical systems and occupants in influencing different aspects of house performance (the "house as a system" concept).

NRC has dealt extensively with fundamentals and design principles relating to moisture problems in its Building Science and Building Insights series of seminars. These have been generally directed to practitioners who are interested in the application of building science.

It should be noted that a number of provincial agencies have had a significant role during this period, both in developing good practice documents and in promoting information dissemination related to moisture problems in buildings.

While the need for dissemination of information on good practice and new technology continues, the extent of technology transfer, including that relating to moisture problems, to the house building and renovation industries over the past ten years, has probably been greater than in any previous decade.

3.6 Changes in Codes and Standards, 1975 - 1990

Appendix F summarizes changes in moisture provisions of the National Building Code of Canada from its inception in 1941 to 1990. Most noteworthy is the extent of increased provisions in the 1990 edition. Since 1975 the principal changes are as follows:

1977

- additional requirements for improved ventilation of low-slope and cathedral roofs in Part 9.
- additional clauses related to reducing indoor air leakage into roof spaces.
- requirement for the provision of mechanical exhaust capability in houses without vented fuel-fired appliances.
- reference to NBCC 1977 Residential Standards for recommended minimum values for thermal resistance.

1980

- the lower portion of mansard-style roofs need not be ventilated, the upper portion required to be ventilated as with other roof spaces.
- withdrawal of references, in earlier codes, to areas to be insulated (i.e. required between heated and unheated spaces, between heated spaces and the exterior, and around the perimeter of concrete slabs-on-grade; not required for masonry or concrete cellar walls, including space between joists, enclosing unfinished space), probably because of publication of the 1978 Energy Measures document.
- withdrawal of reference to NBCC 1977 Residential Standards for recommended minimum values for thermal resistance (see above).
- insulation in factory-built walls to be installed so that it will not become dislodged during transportation.
- vapour barrier need not extend across framing members if the interior finish consists of panel-type material attached to all framing members with an adhesive, in addition to regular fasteners.
- all dwellings to have a mechanical ventilation system capable of providing $^1/_2$ ach (withdrawal of requirement for exhaust systems in houses without vented fuel-fired appliances).

1985

- incorporates separate sub-sections on control of vapour diffusion and control of air leakage in Part 5; previously the reference was to a continuous vapour and air barrier.
- withdrawal of requirement for cross-purlins on top of joists of cathedral-type roofs with slopes of 1 in 6 or greater, where there is a clearance of 75 mm or more between insulation and roof sheathing; 50% of the required vent area ($^1/_{300}$ of ceiling area) is to be near the lower edge and 50% is to be near the ridge.
- where the slope of cathedral-type roofs is less than 1 in 6, the vent area is to be $^1/_{150}$ of ceiling area, with the vents uniformly distributed.
- ceiling insulation is to be installed so that it will not restrict the flow of air through vents.
- all joints in vapour barriers are to be sealed, or lapped 100 mm over framing members.

- holes through vapour barriers for services are to be sealed.
- a new Appendix refers to the importance of air leakage and the need to prevent it, including air leakage around service penetrations, at wall-floor-ceiling intersections, and through gaps due to lumber shrinkage.

1990

- exception allowed in earlier codes, for venting roof spaces of 1-storey buildings, when protected with a Type 1 vapour barrier, is withdrawn.
- new separate sub-sections on "barrier to air leakage" and "barrier to vapour diffusion".
- thermally insulated wall, ceiling and floor assemblies are to be constructed to provide a continuous barrier to leakage of air into wall, floor and roof spaces.
- reference made to a new CGSB standard for polyethylene.
- air barrier materials are to possess the characteristics necessary to provide a barrier to air exfiltration due to pressure differences from stack effect, mechanical systems and wind.
- where air barrier protection is provided by an air-impermeable panel-type material, all joints are to be sealed to prevent air leakage (as in airtight drywall construction).
- where an air barrier is formed of flexible sheet material, all joints are to be sealed, or lapped 100 mm and clamped.
- where an air barrier has a water vapour transfer rate less than the maximum allowed for Type II vapour barriers, it is to be installed at a location where the temperature will not be below the dewpoint temperature of inside air when the outside temperature is 10°C above the $2^1/_2$% January design temperature (no indoor dewpoint temperature is given).
- air barrier protection is to extend across the intersection of interior walls with exterior walls, ceilings and floors that are required to have air barrier protection.
- penetrations of the air barrier are to be sealed to maintain its integrity.
- every dwelling is to have a mechanical ventilation system capable of providing 0.3 ach.
- the Appendix includes additional information on air leakage protection.

- all concrete slabs on ground are to be dampproofed (there is an exception where drain tile is used under the slab).
- dampproofing is to be at least 0.15 mm polyethylene (reference to 45 lb. roll roofing is withdrawn).
- the basement floor slab is to be sealed around the perimeter of the adjacent wall with flexible sealant.
- all penetrations of the basement floor slab by pipes, etc., are to be sealed against water vapour and soil gas leakage.
- all penetrations of the basement floor slab, to drain water from the slab surface, are to be sealed so as to prevent the upward flow of water vapour and soil gas without preventing downward flow of water.
- masonry walls which are not dampproofed on interior surfaces are to have a course of masonry units without voids, or are to be sealed with flashing, at or below the level of the slab.
- where mineral fibre or crushed rock backfill is used against the exterior surface of the foundation wall, it is to extend to footing level to facilitate drainage of ground water to the drainage system.
- the Appendix has information on how to control the infiltration of soil gas.
- all walls and floors separating heated space from the exterior soil are to be provided with sufficient insulation to prevent condensation on indoor surfaces in winter.

The NBCC is developed as a model code of minimum regulations for health, fire safety and structural sufficiency. Nevertheless, in terms of the basic construction of a wood-frame house, Part 9 is also generally regarded by the industry as a guide to good practice. There are sometimes complaints from building science practitioners that Part 9 does not adequately reflect the state of the knowledge. In reviewing the provisions relating to moisture, however, it appears that Part 9 has, for the most part, responded to new knowledge, and to the introduction of new materials and practices, within the five year revision cycle. It has been slow to recognize, explicitly, the need for incorporating a barrier to the exfiltration of air through the envelope, although this was the implicit objective of many of the provisions beginning in 1970. Reference to the provision of air barrier protection was not incorporated into Part 9 until the 1990 NBC, although it was dealt with in the explanatory material in the 1985 NBC. It was dealt with in Part 4 (and subsequently in Part 5) beginning in the 1965 NBC.

During the period 1975 - 1990 a number of new standards that have an impact on moisture control in dwellings have been promulgated. These include:

- CAN/CGSB-149.10-M86, Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method.
- CAN/CSA-C439-88, Standard Methods of Test for Rating the Performance of Heat Recovery Ventilators.
- CAN/CSA-C260-M90, Rating the Performance of Residential Mechanical Ventilating Equipment.
- CAN/CSA-C444-M87, Installation Requirements for Heat Recovery Ventilators.
- CAN/CSA-F326-M91, Residential Mechanical Ventilation Systems.
- CAN/CGSB 51.33-M80 Vapour Barrier Sheet for Use in Building Construction.
- CAN/CGSB 51.34-M86 Vapour Barrier, Polyethylene Sheet for Use in Building Construction.

3.7 Milestones in Moisture Related Activities

The term milestone implies a point at which a recognizable amount of progress has been made in travelling toward an objective. Thus the importance of the milestone will depend on one's view of the objective, the purpose of the journey and its importance. The identification of milestones is, therefore, rather subjective.

A number of interviewees have identified the R-2000 Program as having had more influence on wood-frame construction practice, including that related to moisture control, than any other single factor during this period. The Program produced a new standard of energy efficient house construction, with very low air leakage and without condensation problems. Mechanical ventilation systems provided controlled ventilation with outdoor air to maintain acceptable air quality and relative humidity, while maintaining house pressures relative to outside within acceptable limits.

A large number of builders were trained to build houses to meet the R-2000 requirements. The Program, of course, depended heavily on what had been learned previously, and on technical knowledge that was still evolving. This does not take away from the achievement of bringing all the technical and organizational components together to produce a successful development program.

In terms of understanding the relative importance of moisture problems in the existing housing stock, and some of the principal factors involved, the CMHC national survey (reference 5, Appendix A) is regarded as a milestone. It confirmed the high incidence of moisture problems in the Atlantic Provinces relative to the rest of Canada. It also concluded that moisture troubled houses generally had high indoor relative humidity in winter, and that this condition was more likely to occur in houses without flues. It pointed the way to reducing the probability of the occurrence of moisture problems arising from indoor moisture sources in traditional wood-frame construction.

The CMHC regional test hut studies (references 20, 34, 38, Appendix A) probably represent a milestone in that they demonstrated significant differences in the spring-summer drying rates for wall framing related to differences in climate, as well as to differences in the vapour permeance of the sheathing system. This raises the question of the extent to which the acceptability of construction practices should be dependent on regional climate and the relevance of the NBC in relation to provisions for moisture control. The study also serendipitously identified the initial moisture content of construction framing as a potential cause of moisture damage in regions with poor drying conditions.

The CMHC research program on back-drafting of fuel-fired vented appliances, due to house depressurization caused by exhaust devices, while somewhat peripheral in relation to moisture, might be regarded as a milestone because of its significance for the design of mechanical ventilation and exhaust systems for houses.

In relation to moisture control in insulated basement construction, the work at the University of Toronto, in adapting to Canadian conditions the Scandinavian technology for externally applied insulation, could be regarded as a milestone. Similarly, its work on the application of building science principles to the control of moisture, and related degradation effects, in the retrofit of existing basements is notable. Its work on adfreezing eliminated a major concern about the possibility of frost-heaving damage resulting from the application of insulation to the inside surfaces of foundation walls of heated basements.

There have been many other studies related to moisture during this period, as noted, for example, in Appendices A, B, C, D, E and F. It may turn out, in retrospect, that some of these will appear as important milestones. For example, it is still too early to judge the significance of the computer based moisture model work being pursued independently by NRC and CMHC, or that being developed at the Alberta Home Heating Research Facility. Studies by the University of Toronto on the use of externally applied air barriers of SBPO, and the dynamic wall, might well be judged as a milestone from the perspective of the year 2000. As noted at the beginning, the significance of a milestone depends on the purpose of the journey.

In relation to codes, Part 9 of the 1990 NBC might be regarded as a milestone for its provisions on air barriers, mechanical ventilation systems, and sealing of basements against moisture and soil gas penetration.

3.8 Technical Communications and Co-ordination on Moisture Research and Development

Presentation of papers at conferences of scientific & technical organizations, and their publication in proceedings, is a principal mechanism for exchange of information among scientists and engineers. Exchange of information on moisture research takes place in this way, for example, through the biennial Conferences on Building Science and Technology of the Canadian Society of Civil Engineers (CSCE), the Conferences of the Building Thermal Envelope Co-ordinating Committee and conferences of ASHRAE and ASTM. While this is an essential feature of the knowledge transfer system, the work on which a paper is based has often been completed one or more years earlier.

There is thus no opportunity for technical involvement by others before, during, and immediately after completion of a research project. The regular meetings of the Technical Research Committee of the CHBA are an important exception, where discussions take place on current problems and presentations are made on current work. They are of special importance in relation to house construction. The Canadian Building Envelope Councils, formed in several cities in recent years, are another interesting exception in that their meetings are relatively informal and presentations are generally on current or quite recent work.

Participation in the development of standards has provided another important vehicle of communication between researchers and practitioners. In a number of instances, responsibility for the research required to resolve a technical issue was taken on by one or another of the government agencies involved (e.g. CMHC, NRC, EMR), or was shared.

As already noted, a large amount of moisture research has been carried out by federal government agencies over the past several years. It is not irrelevant to consider what formal and informal vehicles existed for technical communications and coordination between the agencies. Those involved with R and D related to housing were generally CMHC, EMR and NRC. Forintek Canada Corporation also had a considerable involvement. It is a joint venture between the private sectors and government, and derives a considerable amount of its funding from work for federal agencies.

Some of the funds for moisture research were derived from the interdepartmental Panel on Energy Research and Development (PERD). The process of funds allocation was a mechanism for coordination, as it was necessary to put applications for research funding before a peer group for consideration. This, however, represented only a small component of funds allocated to moisture work.

CMHC appointed technical advisory committees for a number of its research projects, which included representatives from NRC, EMR and Forintek. This provided an opportunity to be informed of the project and to offer comments periodically during its course and on completion. The CMHC/CHBA Task Force on Moisture Problems in Atlantic Canada (a steering committee) included participation by representatives of federal and provincial agencies, as well as builders in the region. Widespread communication through attendance at meetings and distribution of reports marked its work.

A number of major EMR projects also had advisory committees. That for the R-2000 program included representatives from CMHC, NRC, industry associations and universities. Advisory committees met periodically during the course of the MAPP and VAPP projects (see Appendix B).

Taken in total, there has been a very substantial amount of communication between those responsible for research activities, and a considerable opportunity to express points of view during the course of a number of specific projects.

For the most part, decisions about research priorities and the terms of reference of projects were established in-house by the management of the various agencies. There were, of course, exceptions when one agency (e.g. NRC) carried out work under contract for another (e.g. CMHC, EMR). Research projects would normally be expected to further the objectives of the agency, and it is therefore appropriate that decisions be made in-house.

It has been suggested that the agencies with the major research programs in moisture would further benefit from more regular organized meetings to discuss the results of on-going research, to exchange views on problems and priorities, and to exchange information on research plans. Examples are the special meeting sponsored by CMHC, in Kingston in 1983 (see Appendix A), and the meeting sponsored by Forintek, in Ottawa in 1991, to discuss its research priorities (see Appendix D). Such meetings have been few and far between.

The possibilities of increased cooperation in areas of common interest could be another topic for such meetings. Different perspectives could be expected, given that organizations have different priorities and time frames, and individuals have different views on what to do and how to do it, sometimes influenced by personal objectives. In order to increase the probability of useful results from such meetings, careful thought should be given to planning and managing the process, building on the experience gained during the process of developing this summary.

4. OVERALL ROLE OF CMHC 1975 - 1990

Moisture related work at CMHC during this period is reviewed in some detail in Appendix A. It is summarized briefly here.

Work in the late 70's and early 80's was largely driven by reports of moisture problems in the Atlantic provinces, including buckling of siding materials. A major national survey concluded that about 1% of the Canadian housing stock had moisture-related structural damage, while about 10% had moisture problems such as window condensation and mould growth on indoor surfaces. The incidence of these problems was significantly higher in the Atlantic provinces than in other regions, and it was concluded that this was related to climatic conditions, including reduced potential for seasonal drying of wall components.

To develop a better understanding of the factors affecting the annual moisture content cycle of wall materials, test buildings which incorporated wood-frame wall specimens, were constructed in three Atlantic provinces. These employed a number of different sheathing materials, with and without strapping beneath the siding. One of the outcomes was observation of very high initial moisture contents of the wood framing. This led to a survey of initial moisture content of framing in Atlantic Canada, and a subsequent national survey.

The Atlantic test buildings indicated relatively slow drying rates of framing components, particularly with sheathing materials having a low water vapour permeance, with mould growth in the cavities of some of the panels. Similar test buildings subsequently built in Ontario and Alberta indicated much more rapid drying and no mould growth.

In parallel with the test building studies, a user-friendly finite difference computer model was developed to predict moisture content changes in wall components. It was meant to model, approximately, many of the moisture flow processes taking place, both in the furred cavity and the insulated wall. Air flow through the wall was not included, as there was no agreement on how it could be easily modelled. Comparison of predictions and test building measurements gave encouraging results but led to the conclusion that better moisture transfer properties and a more complex model were needed. A revised model has been assembled, using a finite element approach, and is awaiting verification trials.

The 1982 national survey of moisture problems, and other subsequent field studies, found that most troubled houses had high levels of indoor relative humidity. This led to some studies on moisture sources, which indicated that moisture stored in indoor materials in summer, and ground-related moisture could be major winter-time sources. A project sponsored by Energy, Mines and Resources Canada used the CMHC results as a starting point in the development of a procedure, for use by the retrofit industry, to assess how much airtightening of houses could be carried out before moisture problems were likely to occur. CMHC has also carried out some work on moisture problems in crawl spaces, and on summer-time condensation in insulated basements of new houses. CMHC has supported demonstration work on a patented system for venting of soil gas, radon and water vapour entering a basement through foundation walls and floor slab. Work has been initiated on the effectiveness of venting of attics in controlling winter-time condensation.

Another series of CMHC projects has been directed to requirements for wall design to reduce air leakage, and thus moisture transport by exfiltration, and to reduce rain penetration through application of rain screen principles. Tests have been carried out to establish the air permeability of wall components, and the airtightness of wood frame wall specimens incorporating a range of air barrier systems and construction details. Other studies have involved evaluation of air barriers for masonry construction and evaluation of structural requirements for air barriers. Concern over the long-term stability of polyethylene film, widely used as a vapour and air barrier in wood frame walls of low-rise residences, led to studies on the condition of polyethylene in service and on measures to achieve extended service life. As a result, the relevant materials standard was appropriately revised.

A computer program and moisture content guideline for materials have been developed to allow determination of airtightness requirements for wood-frame construction to avoid excessive wetting from moisture in exfiltrating air. Variables include sheathing and siding components, thermal properties, weather, indoor hygrothermal conditions, and factors affecting pressure differences due to buoyancy forces. A recent study has provided data on the airtightness of recently constructed houses across Canada.

A number of parallel studies have been carried out on the performance (including moisture) of high-rise residential construction employing steel-stud curtain wall systems, and on the development of good high-rise construction practices. Field examination of masonry clad, steel-stud wall systems revealed problems with corroding studs, wet walls, and fungal contamination. Current studies involve application of recommended construction practices to a major building project, to be followed by monitoring of performance; and determination of the air leakage, air movement and air quality in several multi-storey residential buildings across the country. Airtightness in one building is being determined before and after an airtightening retrofit. The objectives are to establish good construction and retrofit practices for high-rise residential construction.

CMHC activities in the late 70's and early 80's focused the attention of the house building industry on moisture problems with wood frame residential construction in Atlantic Canada. Proposals to resolve the problems of moisture-sensitive sidings by applying them over furring strips, with spaces vented, were opposed by some house builders on the basis that there was insufficient evidence to support this requirement.

This resulted in the formation of the joint CMHC-CHBA Atlantic Moisture Task Force to search for the nature, causes and solutions of the moisture problems. It provided a mechanism for participation by the regional house building industry and local housing authorities. The review of problems by the Task Force led to conclusions that were somewhat at variance with those of some building science consultants involved with the siding issue. While the latter had stressed the importance of the transfer of moisture from indoors as a moisture source, the Task Force emphasized the entry of water from the exterior due to poor detailing, and poor installation of siding systems and flashing. Probably both moisture sources were involved in wetting, and maintenance of high moisture contents, in a number of the observed problems.

Test hut work in the Atlantic provinces, sponsored by the Task Force, resulted in the identification of another moisture source in new construction, wet construction lumber. A subsequent survey of the moisture content of framing lumber in the Atlantic Provinces, sponsored by the Task Force, showed that most lumber delivered to the job site was very wet. This led to a national survey, sponsored by CMHC, on the levels of moisture in framing in houses, as constructed [D10]. It has not been established, however, that wet construction lumber was a cause of the problems that initiated the original concern over the performance of moisture sensitive sidings in the Atlantic Provinces.

The Atlantic test hut study was designed to develop a better understanding of the factors affecting the rate of drying, in wood-frame walls, of framing lumber already wetted by any cause (e.g. condensation during the winter period). The study is described in Appendix A. Principal construction variables were sheathing and sheathing membranes, and the presence or absence of a vented space behind the exterior siding. Insulation used between studs was a secondary variable. All wall panels had a well-sealed polyethylene air/vapour barrier over the inner surfaces of the studs, so that any moisture interchange with the indoors was by diffusion only. Panels were duplicated on north and south facing walls.

All panels had vinyl siding placed both directly against the sheathing, and on vertical furring strips in duplicate panels. The vinyl siding that was originally selected had substantial ventilation openings at each horizontal joint. It was decided (on the basis of computer simulation) that ventilation of the air space between the furring strips would be adequate with the bottom of the space open to outdoors and the top closed. Closing of the top was thought to be advantageous in practice, to avoid venting of the space into the attic, via the soffit. Unfortunately, the siding actually installed had only a small integral vent area, so that interchange of air between the space and outdoors was probably much less than intended. This was discovered only after the tests were well advanced.

The principal test series were designed to determine the time required for construction framing, initially wet in March, to reach a moisture content of 19% during the spring and summer period. Framing used had an initial moisture content generally in excess of 30% (by weight), and usually much higher.

As noted in Appendix A, the relative rates of drying appeared to depend primarily on the water vapour permeability of the sheathing. The furring strips may have increased the drying rate with sheathings having a relatively high permeance (which had the faster drying rates anyway), but apparently had no significant effect on drying rates with sheathings having a relatively low permeance. Thus it would seem to be particularly important to avoid excessive moisture content in framing lumber in Atlantic Canada, whether from initial lumber moisture content, or winter-time accumulation of moisture, when using relatively impermeable sheathing arrangements. While there was a similarity in the results for the panels at all three locations (St. John's, Charlottetown and Fredericton), drying performance at St. John's was generally poorer.

Subsequent observations on similar panels with wood sheathing, initially wet in August, indicated relatively slow drying during the following winter period, particularly on the north wall. It would be interesting to know the rates of drying in the spring-summer period with initially wet wood sheathing, and how these rates are affected by a well ventilated air space behind the siding. It would also be relevant to know if improved venting of the air spaces, created by the furring, would have a significant effect on the drying rates of any of the panels.

The extension of the test hut studies to Waterloo and then Edmonton demonstrated that spring-summer conditions for dissipation of excessive moisture in construction framing are much more favourable there than in Atlantic Canada and initial moisture contents in new construction framing are more likely to be at acceptable levels (although high initial moisture content is still a possibility). Moisture problems in wood-frame walls are therefore less likely. This is consistent with other available evidence. The studies also confirm that some construction arrangements that perform adequately in one Canadian climate may perform less well in another.

While the test hut studies have enhanced understanding of drying of walls, one of the primary issues that led to the formation of the CMHC-CHBA Atlantic Moisture Task Force, the problems with moisture sensitive sidings and the effectiveness of using furring strips, appears not to have been fully resolved. The test hut study indicated that furring strips, in the configuration employed, were not especially effective in promoting drying of wet framing. It did not establish if a well ventilated air space behind exterior siding would provide a significantly better moisture environment for moisture-sensitive siding, or for any underlying sheathing materials, where the moisture source was exfiltrating air in winter, and/or wind-driven rain. One expressed view is that the problems with moisture-sensitive sidings no longer exist because the types of sidings that were experiencing buckling and other types of failures are no longer in use. Another is that the products and application have been improved so that performance in Atlantic Canada is acceptable. There is also the opinion that, while siding failures are less common, hidden problems associated with excessive moisture in sheathing and framing may continue to be widespread with a variety of siding types (see Appendix F).

CMHC is seen to have taken a particularly critical view of the impact of energy conservation programs on moisture damage and indoor air quality in the existing housing stock. To a large extent the issues appear to have been resolved, partly through the application of the results of research by CMHC and others. Similarly CMHC raised a number of technical issues during the development of the R-2000 program. Again, these appear to have been successfully resolved. The resolution of moisture problems in R-2000 houses has provided knowledge applicable more generally to wood-frame residential construction.

A number of building science practitioners see CMHC's role in research and development coordination as having been particularly useful. Moisture problems were dealt with in the context of the "house-as-a-system" approach. CMHC maintained a broad program related to moisture issues, and provided an opportunity for communication with and between others through advisory committees and its contracting out process, as well as through its participation on the advisory committees of other agencies. NRC's role in this coordination and communication in relation to the house building industry is seen, by some, to have declined over the past decade or so (at least in relation to moisture issues). It is seen as having given more emphasis to understanding the detailed mechanisms of moisture movement in materials and assemblies, rather than stressing practice issues. There is a view that CMHC's moisture research program could have benefited from even more involvement in its planning by extra-mural experts.

CMHC is also seen as having produced good training material and good trainers during this period. The implementation of the training, through CHBA, was not seen to have been equally effective, possibly because the extent of volunteerism required was too high. On the other hand, the implementation of the R-2000 training program, again through CHBA, was seen as quite successful.

5. SOME CURRENT MOISTURE ISSUES

5.1 Science and Technology

There will always be science and technology issues related to moisture in residential construction. The perception of issues is dependent on one's role, knowledge, philosophies and interests. Following are some examples:

1. Inadequate performance of moisture sensitive sidings was the primary issue that led to the survey of moisture problems in the Atlantic Provinces in 1982, the issuing of Builder's Bulletin T-6 calling for the use of furring strips under siding (subsequently withdrawn), and the formation of the CMHC/CHBA Task Force on Moisture Problems in Atlantic Canada. There is now a widely held view that the primary source of moisture causing wetting of walls was exfiltration of moist indoor air resulting from wind and house buoyancy forces. The Task Force chose to take a broader view of moisture problems, rather than concentrating on the problems with moisture-sensitive sidings. In its investigative site visits, it emphasized problems resulting from the entry of water from the exterior, due to poor detailing (in addition to problems of interior surface condensation and mould). In its test hut study, the Task Force was concerned primarily with the factors that influence the rates of drying of initially wet framing lumber.

   Some building science consultants (see Appendix F) are of the opinion that the more serious moisture problem in Newfoundland was rotting of sheathing and framing, and that this was not particularly related to the type of siding used. They are concerned that this problem persists, even though hidden by the application of new siding.

   - Have the problems with moisture sensitive sidings in the Atlantic Provinces been resolved (e.g. do wood-based sidings as currently manufactured and installed in Atlantic Canada perform adequately)? If so, what changes in materials, practice, operation and/or maintenance have been responsible? If not, what changes are needed?

   - Have other wall moisture problems (e.g. wet sheathings and framing) identified in the 1982 survey been resolved. If so, how? If not, what steps should be taken?

- Are wood frame houses as currently constructed in the Atlantic Provinces dealing effectively with moisture arising from indoor and outdoor sources, and with construction moisture, as they affect wall performance? If not, what practices are recommended.

- What new practices are needed, if any, to avoid problems arising from initially-wet construction framing? e.g. require the use of S-DRY lumber, or identify construction details to ensure drying in-situ within acceptable time limits.

2. A number of experts recommended the application of siding over strapping as a step in resolving the moisture problems of wood frame walls in Atlantic Canada. The CMHC/CHBA Atlantic Task Force, in its final report, did not support mandating the use of furring strips under siding unless shown, by further research, to provide a significant benefit. The Atlantic test hut study indicated that the use of a marginally ventilated air space behind siding did not contribute substantially to the rate of drying of initially-wet framing lumber (especially with low-permeance sheathing). It did not establish if a well ventilated air space would significantly improve the moisture environment for moisture-sensitive sidings and sheathings.

   Some building science consultants (e.g. see Appendix F) are of the opinion that vertical strapping under horizontal siding, with the air space well vented at top and bottom, can be effective in limiting the adverse effects on sheathing and wall framing of moisture contained in exfiltrating air in winter, as well as in providing a better moisture environment for moisture-sensitive sidings.

   - Are there conditions in Canada where strapping under wood-based siding significantly enhances the performance and maintainability of the siding?

   - Are there conditions in Canada where strapping under siding, or some other positive provision for drainage and ventilation is a necessary feature (or at least, a very desirable one) to minimize rain penetration and/or promote drying of outer wall components? If so, what are they?

   - Are there conditions in Canada where strapping under horizontal siding serves to limit moisture damage to wall sheathing and framing?

3. Painted wood siding is still relatively common on existing houses in Atlantic Canada. Incidental observations, during moisture-problem studies, indicated that paint failure was widespread, and that frequent re-painting was necessary. The problem of paint failure on wood siding, and the role of back-priming, was not investigated.

   - Are there practical approaches for reducing the frequency of failure of paint on wood siding in Atlantic Canada, and elsewhere?

   - How effective is back-priming of wood-based siding in promoting the durability of the siding and the exposed paint coat.

   - Is replacement of painted wood siding with alternate products the preferred solution? If so, what are the appropriate retrofit practices, and are they generally being followed?

4. Platts proposed that the use of low-permeance sheathing papers contributed to some of the observed wall moisture problems in Atlantic Canada, by inhibiting the spring-to-fall drying of moisture stored during the winter, and noted the relatively weak drying conditions in that region. Timusk proposed the use of a vapour-permeable air barrier (e.g. SBPO membrane), under the siding system, as one of the remedial measures. This would have the additional beneficial effect of preventing wind-action from reducing the effectiveness of the insulation, and cooling inside surfaces, particularly at corners. Part 9 of the NBCC, for many years, has included detailed requirements for sheathing papers, intended to inhibit the entry of wind and rain and to allow spring-to-summer drying of moisture in wall components. However, there are no limits placed on the permeance of sheathing and siding materials, except as they may appear in the relevant materials standards.

   - Are current sheathing paper/sheathing system practices adequate for inhibiting air leakage into and out of insulation systems due to wind action?

   - Are studies required to establish the effectiveness of these systems?

   - Are there moisture problems resulting from the use of inappropriate sheathing membranes, or from the use of low-permeance sheathing materials? Should there be some special requirements (e.g. airtightness, drainage, vapour barrier system permeance) when low-permeance sheathing systems are used?

5. Timusk proposed the use of insulating sheathing as one of the remedial measures for the wall moisture problems in Atlantic Canada. Handegord (Prediction of the Moisture Performance of Walls - ASHRAE Transactions 1985, Vol. 91, Pt. 2) analyzed the beneficial effects of insulating sheathing in raising the winter-time temperature at the sheathing-stud interface (normally the condensing plane), and in reducing the total amount of moisture condensing at this location from exfiltrating air. For climates where condensation is likely, he proposed that there should be some resistance to vapour diffusion and air leakage at this location, so that condensation would not occur within the insulating sheathing. If the amount of condensation was likely to be excessive, he recommended provision for drainage. In laboratory studies at the University of Toronto (see Appendix E), in which moist indoor air was injected in the glass-fibre-insulated stud cavity, the amount of condensation accumulating in the cavity (mainly at the interface with the sheathing) was about the same with polystyrene and glass fibre insulating sheathings when the SBPO membrane on the latter was on the warm side. When the position of the SBPO membrane was reversed, most of the condensation occurred within the glass fiber insulating sheathing, with very little in the cavity. It was concluded that the latter position was advantageous when moisture-sensitive sidings are used, as the sheathing can store the moisture harmlessly and it can drain away harmlessly under more favourable conditions. When narrow slots were cut through the polystyrene across the width of the stud spaces, at top and bottom and at two additional levels, the amount of condensation in the cavity insulation was not reduced, and the amount in the sheathing was increased because of frost accumulation in the slots. The Atlantic test hut studies indicated that the rate of drying of initially wet framing was substantially lower with low permeance sheathings (e.g. extruded polystyrene) than with glass fiber sheathing. Differences in drying rates with the two materials in southern Ontario and Alberta test huts were apparently not significant.

    - Are current practices adequate for the use of low permeance insulating sheathings? Should there be any special provisions for their use in Atlantic Canada?

- Which is the preferred location for the SBPO membrane on glass fiber insulating sheathing if there is no effective air barrier on the exterior (i.e. if the joints of the SBPO membrane are not taped or there is no other effective air barrier at this location) or if there is a separate air barrier at this location?
- Is an additional sheathing membrane required if the joints in the SBPO membrane on glass fiber sheathing are taped (i.e. does the taped SBPO membrane meet all the requirements for sheathing membranes)?
- Are there conditions where there should be provision for drainage when insulating sheathings are used?

6. The R-2000 Program and other experience have demonstrated that the construction of relatively airtight wood frame walls is practicable, using polyethylene air/vapour barriers, the airtight drywall approach, or an exterior membrane of SBPO as the principal contributor to airtightness. No wall moisture problems due to indoor moisture sources have been observed. The R-2000 houses have ventilation systems, intended for continuous operation, providing about 0.3 ach. This would normally be sufficient to prevent excessive indoor R.H. These are generally balanced systems, having a more or less neutral effect on pressure differences across the house envelope, and thus not contributing significantly to infiltration or exfiltration.

   CSA Standard F326 covering residential mechanical ventilation systems allows the system to provide an excess of supply over exhaust equivalent to 0.12 L/s per m^2 of envelope. This value was based on estimates of the excess supply air introduced by outdoor air connections to return air plenums, a type of system widely used in various parts of Canada. It is assumed that only a fraction of this finds its way into wall or ceiling cavities, and that the rest passes directly to outside through chimneys, exhaust vents, and cracks around doors and windows. A house pressurization limit of 10 Pa is set, which would occur only with very tight houses (an ELA of about 0.004 m^2 for a small house and 0.034 m^2 for a large house) at excess supply rates less than the equivalent of 0.12 L/s per m^2.

   As noted, a number of experts reasoned that exfiltration of indoor air was the primary source of water causing the wall moisture problems observed in Atlantic Canada. There was certainly considerable circumstantial evidence supporting this belief. Platts noted that average wind velocities in St. John's were highest from the westerly direction, which would induce exfiltration through easterly facing walls. He observed that the wet locations occurred more frequently on these walls (this was not noted in the 1982 moisture survey reports). There was also a higher frequency of problems with flueless houses, which would tend to have exfiltration through upper wall areas. A superficial analysis of wind data for St. Johns suggests that exfiltration on easterly walls due to wind, from October through March, could be equivalent to that resulting from continuous pressurization of the house in the vicinity of 3.5 Pa, depending upon local shielding. A similar analysis of easterly walls in Toronto yields an equivalent house pressurization of about 1.4 Pa. This indicates that the total exfiltration, due to wind through easterly walls could be about 80% higher in St. John's than in Toronto, for similar ELA values. Both locations have an average house buoyancy factor of about 0.75 Pa per meter over the period. Thus the average buoyancy pressure difference across the top parts of walls, and across ceilings of houses without flues is about 1 Pa.

The 1982 survey reported that moisture troubled houses had higher than average indoor R.H., and that a relatively high percentage had electric heat. Analysis of the CMHC/CHBA Atlantic Task Force questionnaire indicated that nearly all moisture troubled houses in the sample had indoor R.H. above 40% at the time of the survey, and about one half had no chimneys. A very high percentage of respondents reported interior mould or condensation (presumably on windows); over one third in Newfoundland reported siding or paint problems, and/or roof space problems.

Platts concluded that very few houses with moderate relative humidity had moisture problems, and that problems originating from indoor sources anywhere in southern Canada could be largely resolved in existing houses by limiting humidities to those that would not result in excessive condensation on inside surfaces of double glazed windows (see Appendix B), as long as major gaps in the air barrier were avoided or corrected.

Controlling indoor R.H. so that excessive condensation does not occur on indoor window surfaces would appear to be a logical upper limit. However, with the increasing improvement in window thermal performance, including edge temperatures of sealed glazing, the R.H. that can be carried is increasing. Where the "cautionary" R.H. in St. John's and Toronto is about 45%, based on the MAPP (see Appendix B), it would be substantially higher based on the thermal characteristics of high performance windows and may then be questionable as a guide for avoiding wall and attic condensation problems.

- What equivalent average pressure differences due to wind action, house stack effect, and mechanical system operation, particularly those causing exfiltration, are wood frame walls and ceilings likely to be subjected to in different parts of Canada throughout the winter? What are appropriate winter-time indoor design humidity ratios for different regions of Canada, now and a decade hence? What wall and ceiling airtightness criteria for typical assemblies, both existing and new, are appropriate for these conditions?

- Are the criteria for allowable excess of supply over exhaust air in CSA Standard F326 reasonable for current house construction or for R-2000 construction?

7. Considerable effort has gone into developing an understanding of and obtaining performance data on the dynamic wall concept at the University of Toronto. Fiberglass Canada attempted to introduce a system based on the concept, but has apparently withdrawn this initiative. At least one tract builder has built a house intended to be operated in the dynamic mode. The apparent potential for energy efficiency utilizing the concept (see Appendix E) catches the imagination.

   - How is the performance of the system affected by differences in climate encountered in Canada?

   - What are the advantages and limitations of the approach based on overall house depressurization? Is it likely to be adopted by builders and home owners?

   - Is the approach more amenable to a factory built envelope system?

   - Are appropriate packaged air heat recovery units available (e.g. to heat domestic hot water)?

   - Are there existing or pending patents that will limit access to the system, and limit the use of public funds for research and development?

   - What priority should be given to further research and development?

8. There have been numerous cases of moisture problems in vented roof spaces over the years, although in the majority of houses such roofs appear to perform satisfactorily in southern Canada. Problems have occurred as a result of high indoor humidities, deficiencies in the air barrier, inappropriate venting arrangements, and increased air pressure differences (e.g. electrically heated houses, multi-storey residences). The National Building Code has strengthened clauses relating to air and vapour flow over the years, and it seems likely that the airtightness of ceiling constructions has increased over the years, along with overall house tightness.

   The vented roof space has not performed very well in northern Canada, at least as executed. It appears that current practice utilizes cathedral type roof arrangements, with an effective air barrier and no vented space, with greater success.

   - Would the vented roof-space system perform adequately in northern Canada if it were constructed to R-2000 airtightness standards, assuming vents were designed to avoid entry of snow?

   - Is it possible to avoid entry of the very fine-grained snow found in this region?

   - Is the moisture performance of roofs with vented air spaces as currently constructed adequate in all parts of southern Canada? Could they tolerate an increase in indoor R.H. (e.g. by 10%)? Are current venting requirements logical?

   - Does the cathedral-type roof system as currently constructed in northern Canada perform adequately? Does this practice have merit for southern Canada?

   - Are the consequences of failure of the primary roofing membrane more serious with the unvented system?

9. Basement moisture problems are among the most common of complaints from home-owners. These include leakage of ground water or rain run-offs through cracks in basement walls or at the wall-floor interface, moisture transfer through floor slabs and walls, and entry of soil gas. Recent

requirements in the NBC appear to go some way toward addressing some of these.

Interior insulation of basement walls has also led to moisture problems due to both construction moisture in the insulated concrete wall and condensation from basement air in the summer (see Appendix A). Condensation on the inner concrete surface in winter is also a potential problem. These problems can be largely overcome by use of good external insulation practices. Interior insulation, however, appears to be the majority choice of builders because of its lower cost. Providing for moisture control appears to present a challenge, because the temperature of the foundation wall in contact with the soil will be below the indoor dew point temperature much of the time. For most of the year, the direction of water vapour transfer by diffusion will be from inside toward the basement wall. Any penetration of indoor air to this surface will add to the moisture transfer. With proper air sealing and a good vapour barrier, the rate of moisture transfer will be very small. Nevertheless, water will condense on the surface at a slow rate and build up, unless it can be absorbed by the foundation wall. If the construction moisture in the wall has been dissipated, and there is no free water on the exterior, the wall will probably absorb the moisture reaching it from the inside and transfer it to the soil. The amounts to be transferred will be very small, something like 0.49 kg per square meter (0.01 lb. per square ft.) per year with a 0.1 mm (4 mil) polyethylene vapour barrier. If condensed, this corresponds to a layer of water about 0.05 mm thick. Nevertheless, the relative humidity at the surface will be close to 100% most of the time, unless the wall is in contact with relatively dry soil.

The NBCC calls for a moisture barrier on the inside of the basement wall, up to grade when it is to be finished. Presumably this is to separate the framing from direct contact with the moisture in the foundation wall, either construction moisture or that subsequently absorbed. It has the disadvantage of inhibiting absorption of moisture transferred from indoors when the foundation wall has come to equilibrium with the soil.

Basement dehumidifiers (or whole-house air-conditioning) are needed in many parts of Canada to avoid condensation (and the growth of mildew) on indoor surfaces of basement walls in contact with the ground and on basement floors. They also reduce the average potential for water vapour transfer into insulated basement walls.

- If requirements and practices referenced in the NBCC for insulating the interior of concrete basement walls are properly applied, along with other requirements, will moisture problems be largely avoided? If not, what practices should be adopted? Is the moisture barrier on the inside surface of the foundation wall, as required by the NBCC, advantageous: most of the time, sometimes, or never?

- Should any framing lumber used for wall finishing be pressure treated?

- Are adequate good practice documents available on avoiding moisture problems in finishing basements?

10. Work was carried out in the early 1980's on the preparation of a document on Measures for Energy Efficiency in Northern Housing. A start was also made on drafting a document for northern construction (see Appendix C). Neither of these was completed.

    - Is there a need for documents detailing good practice for wood frame house construction in northern Canada?

11. Both CMHC and NRC are involved in developing computer models for prediction of the moisture performance of building envelope components. The Alberta Home Heating Research Facility is also developing models to predict hygrothermal conditions in walls and attics.

    - What are the moisture problems and related envelope design issues that require improved methods of performance prediction? Who will use them and why?

    - What are the required features of computer models required for such predictions? What are the current limitations in developing such models? What are the estimated costs and time to develop such models?

    - Will the use of models currently under development enable parametric studies that will adequately assess the limits of indoor/outdoor conditions under which various wall designs will perform satisfactorily? Will it be possible to recommend changes to building practice based on the results of such studies?

- Are there alternative methods for obtaining some of the required information in a shorter period, and/or at less cost?

It has been suggested that building science research and development in the past has been largely reactive. In one sense, technological research and development are reactive by definition. They always are (or should be) concerned with the development of new knowledge or understanding, a method or process, or a product to fulfill a perceived need or exploit a perceived opportunity. They are not, by definition, driven only by the desire to advance knowledge.

Perhaps research carried out to resolve an immediate problem might be classed as more reactive than research carried out to develop knowledge and understanding that will contribute to the solution of a broader range of problems; or a more generalized solution. Similarly, research and development on how to improve an existing product, or process, might be regarded as more reactive than research carried out to develop a new product for an anticipated use. The latter in each case usually requires a longer time perspective, and usually involves more risk (e.g. the research results may be redundant or may be too late, or too early, to be of practical significance; similarly the product may not be marketable for a variety of reasons). There is, however, the possibility of greater reward (more return for the investment).

The extent to which research should be carried out to provide answers to immediate problems, rather than to provide more fundamental knowledge or more powerful tools that may have broader application (or the extent to which development should stress incremental improvement to existing products rather than the creation of new products) would seem to depend on the mission of the organization and the nature of the problems or challenges it faces. Articulation or understanding of mission and goals would appear to be necessary in order for logical identification of current objectives and the development of plans to fulfill them.

For most organizations, research and development are not an end in themselves, but are intended to support broader objectives. Even with an organization like IRC/NRC, research is not intended to be an end in itself, but is carried out to fulfill a stated mission and goals. Universities may be a special case, where the ultimate goal of research is presumably the provision of opportunities for an advanced education.

As noted, embarking on programs and projects that address longer term objectives, or that invest in new development, involves more risk and requires clear articulation of objectives. Professional planning and on-going management are also essentials for success, or for limiting risk. Usually the funds available are limited, relative to the demand, so that making good choices is the initial problem. Unfortunately, either short term or long term projects can be carried out badly.

- What organizations are most appropriate for conducting short term and long term research?
- Should public agencies involved in building research and development be giving more priority to addressing longer term issues? Should they be investing more in the development of new concepts, products and processes?
- What processes, not currently being used, might be helpful in the identification of research and development priorities, and in the planning and management of projects?
- What are perceived as longer term goals worthy of consideration at this time?
- What funding sources exist or could be developed?

5.2 Construction and Retrofit Practice

There has been a significant increase in the average airtightness of tract houses over the past decade, with houses in Winnipeg approaching the maximum allowable R-2000 rate of $1\text{-}^{1}/_{2}$ air change per hour at 50 Pa. At the same time, there is still much room for improvement, particularly in the Toronto and Ottawa regions, and in Vancouver. It is a challenge to construction practice to improve the airtightness of houses in these and other regions. In the recent Canadian survey of airtightness, the average normalized leakage area for 20 Winnipeg houses was 0.91 cm^2/m^2. The average values for Toronto (30 houses) Ottawa (20 houses) and Vancouver (20 houses) were 1.92, 2.07 and 2.87, respectively. St John's (10 houses) was not much better with 1.75 cm^2/m^2.

The installation of mechanical ventilation systems in all houses is now being required by building officials. While considerable advances have been made in the use of heat recovery ventilators for this purpose, particularly in R-2000 houses, there remains a challenge to the manufacturing and home building industries to develop and install effective, reliable, and economical systems for the majority of houses.

The issue of spillage of flue gases from combustion devices sensitive to house depressurization has not yet been fully resolved. Use of naturally-aspirated fuel-burning equipment in tight houses, with a range of exhaust devices for various purposes, would appear to be an anachronism. At the same time, use of high capacity exhaust devices without positive provision for make-up air is also problematic. Resolution of this problem is a challenge for code authorities, manufacturers and builders.

Framing lumber with excessive initial moisture content is being supplied by mills and merchants, and used by builders, particularly in Atlantic Canada. It is a challenge for all to ensure that the wood used in construction is adequately dry when the house is closed in.

Excessive moisture in basements is still one of the most common complaints of new home owners. Systems and materials are now available, which, if properly used, can largely avoid these problems. It is a challenge to the housing industry to improve this aspect of construction practice.

Houses are still being built that do not adequately control the adverse effects on envelope performance of rain and snow. The requirements for good practice are generally known. It is a challenge to the industry to build houses with good flashing and drainage details, and with cladding arrangements that minimize rain penetration and wetting of moisture sensitive-materials.

There is a great variability in the quality of work carried out by retrofit contractors. It is to be hoped that the various components of the industry can provide mechanisms that offer the home-owner some assurance of competent advice and workmanship. The suppliers of products used by the retrofit industry, for example insulation, caulking, insulated sheathings, air barriers, sidings, windows, and ventilation equipment, might take more responsibility in seeing that they are used properly, recognizing the effects of their products on other aspects of house performance.

5.3 Training and Education Needs

The house building industry has been faced with the need to adopt a number of changes in materials, equipment and practices over the past 15 years. Industry training and "good practice" documents, supported by CMHC and EMR, have assisted in this adaptation. The need for training, with appropriate resource material, continues. In areas related to moisture control, there is a need for education and training on improving airtightness, improving moisture control in basements, improving practices in controlling wetting from rain and snow and handling run-off, selecting and installing ventilation and exhaust equipment, and ensuring acceptable construction framing moisture content.

As costs of energy and concerns over global warming increase, it seems likely that the trend toward more energy efficient house construction will continue, and that performance standards comparable to R-2000 will become the norm. This will require ongoing education and training programs.

Despite the investment in energy retrofit in the late 70's and early 80's (e.g. CHIP), there are large numbers of existing houses with RSI 1.2 (R7) insulation (or less) in the walls and RSI 1.8 (R10) in the ceilings. This presents a significant opportunity for upgrading. Programs are required to ensure that it is done properly. A large investment has been made in the development of retrofit standards and guidelines, and in training materials. It seems likely that these will need to be dusted off, and brought up-to-date where necessary, to provide resource material for retrofit training courses.

Ultimately, the home owner is faced with making decisions on repair, retrofit and renovations. The number of alternatives is increasing. It would seem that easily understood, informative material would assist homeowners in making good choices and would increase the probability of obtaining a satisfactory job. Similar material, to assist new home buyers in making informed purchases, would also have merit.

5.4 Driving Forces for Change

Increasing energy costs and environmental concerns are likely to be significant factors over the next decade, with renewed pressure for efficient use of energy and use of energy sources that contribute least to global warming. This suggests that the pressure for improvements in the energy efficiency of both new and existing houses will continue.

There is also likely to be increasing concern over indoor air quality, which may influence the materials used, as well as affect ventilation techniques, and house cleaning and maintenance practices.

Higher costs for accommodation may result in pressure to convert larger homes to multiple dwellings, with higher occupant densities. This in turn will increase moisture and pollutant generation.

The on-going reduction in tariffs and other barriers to trade (i.e. FTA, NAFTA, GATT) is likely to be a factor in encouraging change. Some of the immediate changes in the building products industry appear to have been negative, with the withdrawal of research and development activities of some US-based multi-national companies, and the movement of research and development, as well as manufacturing, of some Canadian based companies to the USA. With the trend toward global marketing, it seems possible that there will be less concentration on producing products to suit the Canadian market, at least by major companies. On the other hand, there may be a wider choice of products originating in other countries, and it will be a challenge to select the most appropriate and adapt them for use in the Canadian environment. It will, of course, be a continuing challenge for Canadian companies to compete successfully in the global market place, and for governments to foster an environment to promote such success.

5.5 Encouraging Innovation

There is a continuing need to strive for improvements in the energy efficiency, indoor environmental quality, safety, useability, durability and affordability of housing for the Canadian population. This generally requires innovation, including technological innovation.

Innovation in manufactured products is usually thought to occur best in economic systems that minimize unnecessary controls, encourage competition and reward success. This in turn is expected to encourage risk taking, research and development in both product and production, and aggressive marketing. While this may be sufficient to produce better vacuum cleaners, it is not likely to be sufficient to encourage significant changes in the wood-frame housing industry.

In the 1960's, following the success of the U.S. space program, which employed the "systems" approach and the "performance concept" in its development program, it was thought that a similar approach might lead to innovation in the housing industry. The notion was that, if housing requirements were expressed in performance terms, rather than in prescriptive terms, the industry would be free of unnecessary constraints, and would respond with innovative housing designs and construction methods. Operations Breakthrough, a major demonstration program, was launched by the U.S. federal housing administration. Proposals were requested for several types of housing in different locations. The National Bureau of Standards (now the National Institute of Science and Technology (NIST)) was charged with developing performance specifications, which in itself was a major undertaking. While much was learned about needs for performance criteria and methods of performance evaluation, and a number of innovative schemes were put forward and implemented, it is not apparent that this had any major continuing influence on the industry as a whole. This is not to say that expressing requirements in terms of performance is not a desirable goal; it alone is apparently not sufficient incentive for innovation in the housing industry.

It appears that the introduction of significant change, and performance improvement in residential construction, requires: a commitment on the part of the public sector; the articulation of goals; the development of the technology required in association with the private sector; and a joint public/private sector implementation program. In the process there may be a requirement for new mandatory standards, changes to building codes, new design and construction manuals, and new education and training programs. This type of co-ordinated effort is required to effectively address the moisture issues identified in this report.

The idea has been advanced that improvements to our Canadian wood frame residential building practice will be helpful in encouraging export sales for Canadian business, for example to Japan and other far-east countries, and eastern Europe. Certainly improvements could be helpful to companies that are targeting such potential export markets. It would seem, however, that there should be an assessment of the specific opportunities for Canadian companies before publicly funded research and development is justified on the basis of improving export potential. Perhaps there is a need for improved communication between the public agencies responsible for encouraging competitiveness and exploration of trade opportunities by the Canadian building industry (including the service sector), and those agencies responsible for allocating and utilizing public funded research and development. One objective would be to make it possible to include exploitation of foreign market opportunities as a factor in establishing research and development priorities. There must, of course, be viable Canadian industries that can exploit the results of such research and development in developing products and services to be offered on world markets.

APPENDIX A

MOISTURE RELATED WORK AT CMHC

1975 - 1991

Moisture Related Work at CMHC 1975-1991

CMHC, since its inception, has been concerned with practical approaches to avoiding moisture problems in NHA financed housing. Good construction practices were intended to be reflected in the Residential Standards, first published in-house by CMHC, and later published by the Associate Committee on the National Building Code (subsequently in Part 9 of the NBCC). Problems with house performance were brought to the attention of CMHC's national office by regional staff and, when necessary, special directives (e.g. builders' bulletins) were issued to deal with the problems. New products and systems were evaluated by headquarter's technical staff and, if evidence warranted, listed for acceptance. Field inspectors attempted to ensure that houses were constructed in accordance with the appropriate standards and directives, and that only listed products were used. Advice on methods of evaluation and on resolution of problems was provided by research agencies, such as the Division of Building Research, NRC and the Forest Products Laboratory (now Forintek). Many national technical issues were resolved through the CMHC process.

Changes in the organization of technical operations at CMHC beginning around 1975, as well as changes in relationships with research agencies, resulted in a more proactive approach by CMHC to technical research and development. This coincided with a great increase in research and development funding on energy R & D, including that related to buildings, through EMR and provincial energy agencies. One of the results has been the development of substantial capabilities for building research and development work by private consultants across Canada.

Since 1975 the Corporation has built up an extensive in-house capability to plan and manage contracts for the conduct of research and the implementation of housing technology into practice. CMHC staff articulated the concept of "the-house-as-a-system" to help to explain the interactions of the house, and its components, with the indoor and outdoor environment, and to understand the problems caused by these interactions and the symptoms they produce. This concept was applied to studies on both moisture and combustion venting problems. Extensive contract work related to moisture problems began in the late 1970's. An early survey on moisture conditions in new houses [1], by

Scanada Consultants Ltd., concluded that 5% to 10% of new residential construction was experiencing noticeable condensation problems. Occurrences were in all regions. More cases of wall condensation than in the past were noted, and electrically-heated houses without flues were more susceptible.

This was followed by a survey of moisture-troubled houses in Newfoundland [2]. It was concluded that 20% - 30% of electrically-heated houses without flues, with moisture-susceptible sidings, were experiencing moisture damage. Wetting was attributed to exfiltration of air rather than to wind-driven rain. Complementary studies by affected siding manufacturers were also being undertaken. A 1981 in-house report [3] summarizes the problems as perceived at that time. These were primarily buckling of horizontally lapped hardboard siding, and saturation of the fiberboard backer in certain designs of aluminum siding. The problems were thought to be exacerbated by the use of flueless heating systems, tighter house construction, together with higher insulation, and reduced opening of windows (to save energy). It was thought that between 2000 and 6000 units might be experiencing problems. It was proposed that a survey should be carried out to determine their extent, and that studies should be conducted to investigate the theory of exfiltration as the moisture source, and the design/material requirements for suitable wood-frame construction in Newfoundland.

The siding manufacturers association, the Canadian Siding, Soffit and Rain-Goods Manufacturers Association (CSSRMA), were recommending that strapping should be applied under moisture-susceptible siding. It was proposed that the effectiveness of this should be determined, rather than discontinuing use of the siding in question. A strapping detail that was closed at the top to prevent flow into the soffit space, for use with siding having a substantial amount of integral venting, was one of those proposed by CMHC. While the manufacturers supported the use of strapping as an immediate measure, they held the view that the ultimate solution called for reduction of indoor humidity, through ventilation and source control, and reduction of exfiltration.

In 1982 CMHC sponsored a major project on moisture-induced problems in NHA housing [5]. Part 1 was an analysis of the results of a cross-Canada telephone survey, to identify the extent of moisture related problems; plus a field survey of 201 moisture-troubled houses across Canada to identify the nature of the problems, together with relevant house and occupancy data. The problems observed were classed as:

- buckling and warping of siding and other siding problems;

- high moisture content readings in sheathing;
- mould and mildew within the house;
- high moisture content readings of materials within the wall system;
- high levels of window condensation and window frame damage; and
- mould, mildew and high moisture readings in the attic space.

Average characteristics of problem houses, when compared to the average housing stock, were revealing:

- high occupancy (4.1 vs 2.9);
- high relative humidity (49% vs 35%);
- high percentage of electric heat (81%); and
- relatively new (1975 vs older).

Analysis of the data suggested that:

- Problems in the siding and sheathing complex appeared to be related to the climate condition found primarily in Newfoundland, with poor drying conditions in the spring, low temperatures in the drying season, a high incidence of driving rain, and low energy from the sun.

- Mould and mildew on interior surfaces appeared to be related to the high levels of internal moisture generation (presumably the high dew point temperature of the indoor air). The problem was noted to occur often in areas of high wind exposure, suggesting cooling due to leakage of outdoor air into the wall cavity.

- Window condensation was observed in very cold regions and in areas using single glazing. Newfoundland did not report a high incidence of window condensation problems (this is not consistent with some other field studies in Newfoundland where nearly all moisture troubled houses in the sample had excessive window condensation). It may be that window condensation is so common there that it was not reported as a problem.

- High moisture content readings in the wall system appeared to be related to climate, particularly cold weather. A higher incidence on the 2nd floor was taken to be indicative of exfiltration.

- Mould and mildew in the attic requires a combination of warm conditions and moisture. High moisture content in attic structural members correlated with colder weather, low solar gain and driving rain, as found in Newfoundland. Both types of problems were found to be associated with poor attic ventilation.

The data were analyzed to predict the incidence of moisture induced problems. Based on the average age of the houses in the data file, the expected incidence for single and multiple units in Newfoundland was about 30%. In the rest of Canada the expected incidence generally varied from less than 0.5% to about 2%. An exception was nearly 9% for multiple dwellings in British Columbia.

Part 2 of the report, prepared by J. Timusk, assessed the data from building science principles, and offered some possible solutions. These included:

- reduction of indoor humidity;
- use of improved air barrier systems for the ceilings and walls (with a preference for a vapour permeable air barrier on the outer face of the studs);
- use of insulating sheathings;
- use of furring strips under siding (rainscreen); and
- provision of improved control of basement moisture.

Part 3 of the study considered the practicality of using a passive vent stack as a means of reducing indoor humidity and raising the neutral pressure plane in electrically-heated houses in Newfoundland. It was concluded that it could not be depended upon to lower relative humidity sufficiently and that it would add significantly to heating costs. It was also found to be noisy in some instances. Mechanical ventilation, particularly with heat recovery, was seen as a better solution, but one with high capital cost. Available dehumidifiers were not effective for humidities below 50%.

In August 1982, CMHC issued Builders' Bulletin T-4, calling for the use of furring strips under exterior horizontal or panel siding of wood, wood products, plastic or metal in Newfoundland.

In December 1983, CMHC sponsored a meeting of technical experts to consider the results of the study of moisture-induced problems in NHA housing [5] and to consider priorities for near future studies. Two streams of studies were proposed: performance of passive vents or equivalent active flues; and drying characteristics of different wall sections.

In November 1983, R.E. Platts, one of the participants in the meeting, presented a paper on "Wet Walls in Canadian Houses: Problems, Solutions, Policy" [6], based on work carried out for CMHC [1] [2] [4] [5] and the industry. He argued strongly that the problem was primarily a coastal one (particularly Newfoundland), involving flueless houses, and that the wet locations generally correlated with breaks or gaps at the interior face of the wall. He noted that flueless houses have lower rates of infiltration and, therefore, higher indoor humidities. They also have lower neutral pressure levels, with exfiltration through upper wall levels. He also argued that the wet locations occurred most frequently on east facing walls, which corresponded to the lee (exfiltrating) side for the highest frequency winds. They were often high on the wall, under the soffit. He concluded that the moisture source was primarily indoor air. The weak spring and summer drying conditions were another contributing factor. Drying was further diminished by vapour resistant sheathing papers (roofing felt was often used). There were also higher water tables and, therefore, higher rates of moisture generation in basements. He recommended using vapour permeable sheathing papers, strapping under siding, and installing an exhaust fan or passive flue for ventilation.

While there has been general acceptance of the logic of these arguments, there are some who believe that the effects of wind-driven rain in Newfoundland should not be discounted entirely. The highest frequencies of wind combined with rain are from N, NE, E, and SE directions, which indicates that east facing walls could be subjected to heavy wetting. This would at least contribute to wetting of moisture-sensitive sidings, and would reduce the rate of drying.

By 1983, CMHC, with the Canadian Siding, Soffit and Rain-Goods Manufacturers Association (CSSRMA), was considering the possibility of requiring the use of furring strips under siding beyond Newfoundland. Builders' Bulletin T-6 was issued by CMHC in May 1984, to take effect in September, requiring furring strips under siding in all Atlantic provinces. CHBA objected to the proposed requirement, arguing that the need for and the efficacy of furring strips had not been demonstrated, and that they would add unnecessarily to construction costs. T-6 was subsequently withdrawn and a joint CMHC/CHBA Task Force was formed, in February 1985, to investigate the causes of and solutions to moisture damage in Atlantic Canada, with special emphasis on determining the efficacy of installing siding on furring strips. One of the Task Force's early jobs was to help in the development and review of an advisory document [10] subsequently published by CMHC.

The Task Force [21] carried out site visits to moisture-damaged houses, as well as new and rehabilitation projects, when meeting at St. John's, Charlottetown, Fredericton, and Halifax. It also initiated the compilation of a moisture problem data base through the CMHC Atlantic Regional Office in Saint John's, and oversaw a research project involving observations on moisture performance of test walls in huts constructed at Fredericton, Halifax and St. John's. It also commissioned a survey of the initial moisture content of framing lumber in new houses in the Atlantic Region when it became evident that such moisture could be a significant factor.

As a result of the site visits it was concluded that:

- The entry of water from the exterior due to poor detailing, poor installation of siding systems and flashing and lack of regular maintenance, were frequent factors in walls damaged by moisture.
- Many of the houses visited exhibited mould, mildew and condensation in the interior surfaces of exterior walls and relatively low indoor temperature in troubled areas.

A general conclusion was that the incidence of moisture-related damage in Nova Scotia, Prince Edward Island and New Brunswick appeared to be lower than in Newfoundland.

In the attempt to develop a data base on moisture-troubled houses, only 117 questionnaire forms were completed, mostly from Newfoundland and Nova Scotia; in this sample, 79% were post 1970; 88% were single-family; 53% were without chimneys; 67% had exhaust fans; 93% reported indoor humidities above 40%. In Newfoundland the reported problem locations were: 95% interior mould or condensation; 11% framing or sheathing deterioration; 36% siding or paint; and 38% roof spaces. The corresponding figures for Nova Scotia were: 80%, 6%, 24% and 37%, respectively.

The objective of the test hut study ([19], [20] and [21]) was to compare the moisture performance of a variety of wall assemblies exposed to actual weather conditions, in order to obtain an enhanced understanding of the principles affecting drying, and an insight into appropriate materials and methods for house construction in cool, wet climates, particularly the use of furring strips under siding. Identical huts were constructed at the three locations.

Horizontal vinyl siding was used on the exterior of all panels. Apparently, the steering committee had decided that the principal issue was whether the use of furring strips assisted in the drying of interior wall components (i.e. sheathing and framing) not, specifically, whether it contributed to improved performance of wood-based sidings. There was some thought of using such sidings in a second round of test hut trials but this did not take place. Five different wall assemblies were used, three of which were constructed both with and without furring strips. The air spaces between furring strips were closed to the outdoors at the top and were open at the bottom. Closing of these air spaces was thought to be desirable in practice, to minimize the flow of moist air from the spaces into soffit vents. In order to obtain adequate venting of the spaces to outdoors, a vinyl siding with substantial integral venting area, at each horizontal joint, was chosen. Computer simulation had indicated that venting with such siding would be adequate. Unfortunately, the siding actually used had a very small integral venting area, so that ventilation of the space was significantly less than intended. The trials were well advanced before this was discovered by the Task Force.

Three of the five assemblies used glass fibre batt insulation, one used wet-spray cellulose insulation, and another used expanded polystyrene. Sheathing systems employed were: wafer-board with asphalt-impregnated sheathing paper, semi-rigid fiberglass with spun-bonded polyolefin membrane, extruded foamed polystyrene board with SBPO membrane and with asphalt-impregnated sheathing paper, and expanded polystyrene board with asphalt-impregnated sheathing paper.

A well-sealed 4-mil polyethylene air/vapour barrier covered the edges of all panels as well as the inner surface of the studs so that moisture interchange between panels, as well as air and water vapour movement between indoors and outdoors, were minimized. The choice of a tightly installed air/vapour barrier was deliberate, in order to limit the transfer of water vapour across the membrane to flow by diffusion. Gypsum board covered the inside surfaces of all panels.

Test panels of each type of construction were duplicated on north and south exposures at the three sites. Indoor conditions were maintained at 20°C during the heating season and R.H. was not allowed to fall below 60%. Considering the effectiveness of the air/vapour barrier as constructed, the interior RH was unlikely to have had a significant effect on the observed moisture performance. The virtual elimination of air movement through the wall (between outdoors and indoors) could also be expected to greatly reduce the potential for rain penetration.

It was intended to condition the framing members to a moisture content not less than 25 - 30%. This was found to be unnecessary as the locally available lumber at the three locations had values well in excess of the minimum (this prompted the survey of framing lumber moisture content). The moisture in the framing lumber was the primary building moisture source. Determining the time required for the moisture content to decrease to the maximum acceptable value of 19% was the primary objective of the study. Data was collected from March 1986 to August 1987.

All test panels of three of the eight types of construction dried to 19% within the monitoring period. All but one panel of three other types dried to 19% during the period. In another type, only three of the panels dried to 19% and in the eighth type, none of the panels dried to 19%, although all exhibited some drying. Test panels with sheathing systems that were more permeable to water vapour dried more quickly than those with less permeable sheathing systems. The permeability of the sheathing system appeared to be the most significant factor in the rate of drying and the final moisture content of the framing. Most panels which stayed wet for an extended time exhibited some fungal growth in the framing and wood-based sheathing materials. It was concluded by the Task Force that the furring strips, in the configuration tested, had no significant effect on the rate of drying or on the final moisture content to which the framing and sheathing materials dried during the monitoring period. One member holds the view that, while the effect of the furring strips might not be regarded as significant, the test results indicate that there was usually a noticeable improvement in drying performance over similar panels without furring strips. The frequent occurrence of conditions leading to condensation on the back side of the vinyl siding led to the suggestion by the Task Force that furring strips under siding might be beneficial in preventing moisture accumulation in wood based siding and sheathing materials.

The survey of the moisture content of framing lumber in Atlantic Canada [26] was intended to determine if the use of lumber having a high moisture content was wide spread. Wall studs, originating from seventeen saw mills in three provinces, were checked at three different times of the year. The studs were in houses under construction. 90% had a moisture content in excess of 19% and 54% of these studs were beyond the fibre-saturation point. Some of the houses had been framed for up to two months and were ready to be closed in. It was concluded that the lack of availability of dry framing lumber is a significant contributor to the moisture load in wall systems in Atlantic Canada.

During August 1987, 19 x 140 mm wood sheathing with SBPO membrane was used to replace the glass fibre sheathing in two panels on both north and south facing sides of the test hut in Halifax. The vinyl siding was placed against the sheathing in one pair of panels and over furring strips in the other pair. All other panels remained the same. Monitoring of moisture conditions was continued through March 1988 [22].

The initial moisture content of the wood sheathing on the two north wall panels was well over 30%, while on the two south panels it was just under 30%. The sheathing of both non-furred and furred panels on the north side had a moisture content in excess of 20% at the end of March. The rate of drying appeared to be somewhat greater with furring. Sheathing on the south wall had dried to about 15% by the end of March. If anything, the furring appeared to slow down the drying slightly on the south side, (possibly because of the cooling effect of the air space on the sheathing under solar exposure conditions?).

Test huts have subsequently been constructed in Edmonton [35] and Waterloo [39] to obtain evidence on the moisture performance of residential walls in other climates. Some of the wall panels used in both locations were duplicates of those used in the Atlantic test huts. In panels where furring was used behind siding, the spaces were left open at both the bottom and the top, so that there was significant venting area regardless of the airtightness of the siding. This raises some question about the compatibility of their performance with similar wall panels in the Atlantic test huts. Other siding reflected common regional practices. The projects have demonstrated that the climates in these locations provide substantially better conditions for drying than those generally found in Atlantic Canada. It was also found, in a CMHC supported survey (see Appendix D), that available framing lumber in these locations generally has a much lower moisture content than that found in Atlantic Canada. Drying time for walls was therefore substantially less. In the Atlantic test hut project, framing members in panels with wet-sprayed cellulose (250% initial moisture content by weight) took up to two years to dry to 19% moisture content (by far the longest of all panels tested). In Edmonton, framing in walls with this insulation having an initial moisture content of 50% by weight, dried to 19% within 2 to 3 months. A lower initial moisture content of both the framing and the insulation were favourable factors, in addition to climate. Measurements, in a typical Edmonton residence, of moisture content in walls insulated with wet-sprayed cellulose indicated that framing recovered to its pre-insulation moisture content within 6 months [32].

At Waterloo the framing was pre-conditioned to a moisture content above 19%. Panels were constructed of ten different wall systems, with three insulating-type sheathings and three non-insulating. All had polyethylene air/vapour barriers meeting the requirements of the NBC, covered with gypsum board. Cladding was vinyl siding and brick. Indoor conditions were maintained at 20°C and 50% RH during the heating season. Based on observations over 11 months, it was concluded that wall framing could be expected to dry to 19% moisture content in 90 days, and to an equilibrium of 9% to 12% in 5 months, or less. No fungal growth was evident in the wall cavity at the end of the period. Drying rates generally increased with increasing vapour permeance of the sheathings.

A revealing experiment, on behalf of CMHC, was carried out on three wall assemblies in the test hut facility of the NRC's Institute for Research in Construction [25]. Panels in this case were all insulated with glass fibre insulation in the wall cavity and, covered on the inside with polyethylene and transparent Plexiglass. Sheathings were rigid glass fibre, extruded foamed polystyrene, and waferboard. The siding was 5 mm plywood on 20 mm vertical strapping in all cases, providing a ventilated air space open to outdoors at bottom and top.

The principal objective of the experiment was to determine the moisture performance of the panels when there was a known rate of exfiltration into the wall cavity. The hut was therefore pressurized continuously at 10 Pa with respect to outdoors, and orifices were installed on the inside, near the top of the stud spaces, allowing controlled flow through the indoor cladding and polyethylene, into the wall cavity. Vent holes, 140 x 235 mm, were cut through the sheathing toward the bottom in all assemblies, as well as toward the top in alternate stud spaces of two assemblies, so that the orifices provided the main flow resistances. Two sizes of orifices were used with each assembly, providing flow rates of about 0.12 L/s and 0.7 L/s (representing respectively, a heat loss of about 0.5 and 3 times the cavity conduction heat loss at no-flow conditions).

The observation period was from January through March. Inspection of the cavity through the transparent interior revealed no condensed moisture at any time. The moisture content of the bottom plates of the glass fibre and waferboard sheathed panels did not change throughout the period (between 9% and 12%), while that of the foamed polystyrene sheathed panels was more variable, increasing to above 20% at times in some stud spaces. There was no firm explanation for this. In all assemblies, inspection of the space between sheathing and siding, after a cold spell, showed large quantities of frost at the top. During mild periods this air space was cleared of the frost. The moisture content of the waferboard increased to about 20% by weight; the glass fibre and foamed polystyrene sheathings remained free of moisture. Very little condensation was observed on the surface of the glass fiber cavity insulation, as seen through the exterior vent holes. The results raise the possibility that, with some wall assemblies, the use of furring strips, providing storage of frozen condensate and subsequent drainage, would be helpful in controlling the damaging effects of moisture in exfiltrating air, at least where conditions for periodic melting of frost are present.

During 1984-85 CMHC sponsored work on the performance of polyethylene as an air barrier. One of the studies [9] was concerned with the effect of different installation methods on the ability to provide and maintain air leakage resistance at joints. This raised some questions about the effectiveness of sealants typically used between overlapping joints. The R-2000 Program relied heavily on the performance of polyethylene as an air barrier, and preliminary durability studies raised serious questions about service life. CMHC carried out complementary studies [7], [12], which ultimately resulted in a revision to the CGSB standard to ensure acceptable properties related to durability.

The search for causes and solutions to the wet outer wall conditions encountered in Newfoundland emphasized the limitations in methods for predicting the moisture performance of outer wall components in different assemblies, exposed to different indoor and outdoor conditions. CMHC therefore initiated the development of improved methods of prediction [11], [13], [14], [20] which resulted in a computer program, WALLDRY [24]. A project was then carried out to compare WALLDRY predictions with the Atlantic Canada moisture test hut data [31].

In the course of this project it was determined that some corrections should be applied to the original moisture content readings. Analysis of the corrected data confirmed that the vapour permeance of the sheathing was the decisive factor in determining the drying rates of the framing. Panels with higher permeance sheathings dried more quickly than those with lower values. The effect of the furring on drying of panels with low permeance sheathing systems was not significant (in the particular configuration employed). However, panels with high vapour permeance showed a decrease in drying time when furring strips were used behind vinyl siding. It was also confirmed that south facing panels dried more quickly than north facing ones.

The comparisons of WALLDRY predictions with measured moisture content profiles led to some changes in the assumed moisture properties of the wood studs. With the modified properties there was reasonably good agreement with the measured values for more than half the panels. Deficiencies were encountered in predictions for panels with high diffusion resistance (low permeance). There were also deficiencies in predicting heat transfer resulting from exposure to solar radiation and night-sky conditions, and to changing surface convection conditions (wind). Some significant improvements have subsequently been made and WALLDRY 2 is now waiting verification trials. A new program, WALLFEM, allowing for heat and moisture transfer in two dimensions, is in the planning stages.

The national survey of moisture problems [5] found that most troubled houses had high levels of indoor relative humidity. This led to some studies to determine apparent short-term moisture generation rates in houses, using measured values of air infiltration plus indoor and outdoor humidity ratio [8] [16]. Apparent moisture source strengths for houses generally increased with increasing rates of air change. They also increased with decreasing outdoor humidity ratio. The range of values was high, from 1 kg/day to 140 kg/day in the first study. In the second study there were some negative values, with positive values up to 76 kg/day. The higher values greatly exceed those due to occupant's living habits. The results raise questions about the influence of moisture storage on short-term tests, and the strength of below-grade sources. One project dealt with soil gas sampling techniques [17].

A number of CMHC projects have dealt with control of moisture in basements and crawl spaces. A study of crawl spaces of low-income houses [15] identified conditions that can result in high humidity ratios and excessive moisture in headers and sill plates. Appropriate drainage, moisture barriers on the foundation wall, and low permeability ground covers are essential. Ventilation with outdoor air in spring and early summer can represent a net moisture source.

A study [18] was made of occurrences of excessive moisture on indoor surfaces of insulated basement walls of new houses in Winnipeg during the spring and summer. The nine moisture-troubled houses had full-height interior insulation installed prior to house occupancy, along with a polyethylene vapour barrier. It was determined that the temperature of indoor surfaces of basement walls of many Winnipeg houses is below the dewpoint temperature of basement (and outdoor) air during warmer periods of the year. In the case of the new houses, basement insulation systems had been applied before the concrete had lost its excess moisture, and the rate of drying was inhibited by the presence of the insulation and air/vapour barrier. Often the air barrier did not prevent circulation of basement air between the insulation and the concrete, resulting in free water on the surface, which wet the insulation and the framing, particularly the bottom plate, and pooled on the floor. To remedy the situation, the wall had to be opened, the insulation removed, and the concrete exposed for several months to dry before reconstruction. The concrete observed in older houses was dry and could absorb condensate that occurred periodically. It was concluded that, to avoid the problem with new houses, excess moisture in the concrete should be allowed to dissipate before finishing the inside of the basement wall, and that the air/vapour barrier should be applied so as to inhibit air circulation. Alternatively, a system of exterior insulation could be used, which leaves the concrete free to dry from the indoor surface.

CMHC has supported demonstration work on a patented system, ECHO, to vent soil gas, radon and water vapour transferred through basement walls and floor slabs. It may have merit for dissipating moisture in concrete of new finished basement walls.

Another project [27] identified the advantages of using exterior drainage-type insulation systems in improving the moisture performance of basement walls. CMHC has been a contributor to a recent project [42] sponsored by the OHBA, to identify practical below-grade insulated construction systems to avoid moisture problems and reduce energy requirements. It has also sponsored studies on storm water control and the protection of basements against flooding [43].

CMHC has carried out another series of projects concerning requirements for wall design to reduce air leakage, and thus moisture transport by air exfiltration. Tests have been carried out to establish the air permeability of wood frame wall components, the airtightness of wood frame wall specimens incorporating a range of air barrier systems and construction details, and the ability of these air barrier systems to withstand wind loads [23], [41]. Methods and performance requirements for evaluating air barriers for other types of walls have also been developed [36] [40].

A computer program and limiting moisture content guidelines have been developed to allow determination of airtightness design requirements for various wall constructions to avoid excessive wetting from moisture in exfiltrating air [28]. Variables include sheathing and siding components, thermal properties, weather, indoor hygrothermal conditions, and factors affecting pressure differences due to buoyancy forces.

CMHC has participated in a recent (1989) cross-Canada survey of the airtightness of 194 new houses [34]. Results were compared to a similar survey of 200 houses by EMR in 1982/83. As in the previous study there was a large overall range of airtightness values from 0.98 to 11.3 air changes per hour at a pressure difference of 50 Pa. On average, the loosest houses were in Vancouver, and the tightest in Winnipeg, as in the previous survey. In all locations across the country the average tightness was equal to or greater than before and, overall, there was a reduction of about 30% in leakage characteristics during the 6 to 7 year period. This has a number of implications relative to design for exfiltration and condensation, humidity control and indoor air quality. CMHC has sponsored a number of research projects related to the design and use of mechanical ventilation systems for houses [44]. These have relevance for the control of indoor humidity, as well as for other aspects of indoor air quality.

Studies have been initiated on the airtightness of envelopes of multi-storey residential construction [33] [38]. This will provide information on the potential for moisture problems arising from exfiltration. Currently, the airtightness of one building is being determined before and after airtightening. Studies have also been carried out on the performance, including moisture, of high-rise residential construction employing steel-stud curtain wall systems and on the development of good construction practices [38]. Field examinations of masonry clad, steel-stud wall systems [29] revealed problems with corroding studs, wet walls, and fungal contamination. Current studies involve application of recommended construction practices to a major building project, to be followed by monitoring of performance. The overall objective is to establish good construction and retrofit practices for high-rise residential construction.

APPENDIX B

MOISTURE RELATED WORK AT EMR
1975 - 1991

Appendix B

Summary of Moisture Related Work at EMR

Since 1975, in the course of pursuing goals related to security of energy supply in Canada, and, more recently, reduction in the production of pollutants contributing to global warming, EMR has engaged in major programs concerned with efficient use of energy in buildings, and reduction in the use of oil for heating buildings. Those primarily concerned with residential energy conservation were:

- the Canadian Home Insulation Program (CHIP), which encouraged the retrofit of existing houses with insulation and airtightening through subsidies to participating home owners,
- the Canadian Oil Substitution Program (COSP), which encouraged the retrofit of existing homes using oil heating with heating equipment using other fuels, again through the use of subsidies,
- the Home Energy Program (HEP), which provided technological support to the CHIP and COSP programs, and to the industries involved with energy retrofit of residential buildings (part of this was provided, at one time, through the Building Energy Technology Transfer program, BETT), and
- the Super Energy Efficient or R-2000 House program, which developed performance standards, technological support, and a delivery system for houses intended to provide a new, higher level of energy efficiency, in association with the house building industry.

EMR has had many other programs which have impacted on housing technology, including Enerdemo, which supported projects demonstrating energy efficient technologies. The Program for Energy Research and Development (PERD) has provided major funding to a number of federal agencies for energy R and D, some of which has been related to moisture problems in residential construction.

EMR groups, responsible for the technical effectiveness with which the CHIP program was implemented, supported the development through CGSB of a handbook on insulating existing homes for energy conservation, along with supplementary manuals dealing with the use of cellulose, mineral wool and urethane. CGSB operated a certification program for insulation contractors as part of the CHIP program. A manual on the proper application of insulating siding was also prepared through CGSB. EMR supported the preparation of an air sealing manual, detailing good practices in the air sealing of existing houses. This document was originally drafted by the Saskatchewan Research Council (SRC), and was ultimately published by CGSB. Complementary test methods and requirements for weather-stripping and indoor caulks and sealants were drafted by SRC for ultimate processing by CGSB.

There was concern, expressed by technical staff at CMHC, NRC, and elsewhere, that insufficient attention was being given to the potential impact of the energy conservation and oil substitution programs on moisture problems in houses. An early initiative by EMR to consider this issue resulted in a report [1] which attempted to assess the risk of moisture damage resulting from the application of residential energy conservation and conversion to flueless heating.

Based on the evidence then available, it was estimated that the incidence of moisture damage arising from conversion to heating systems with little or no flue effect was 130,000 houses over 30 years, or 4,300 houses per year (assuming no counteracting steps were taken). This was based on the assumption that, over this time period, 4.25 million houses would be converted. It was further estimated that all other energy retrofit measures would cause a moisture damage incidence of fewer than 2900 houses per year, for a total of 7200 houses per year. This amounted to 2.6% of the existing housing population.

The solution was seen to be relatively straightforward: to implement effective air sealing measures at the time of retrofit, and to control indoor humidity through appropriate ventilation strategies. The report proposed that studies to determine the impact of various measures on moisture problems should involve houses that were already marginally overstressed with moisture.

Another report [2] provided a summary of the experience of a major air-sealing contractor with house moisture problems in southern Ontario. The principal problems encountered were excessive moisture in attics, and window condensation. Attics with cellulose fill insulation appeared to be less prone to moisture problems; those constructed before 1970 (before the Ontario Building Code called for a continuous vapour barrier over top plates) were more prone. Houses occupied by some ethnic groups that imposed high moisture loads were also prone to problems. About 1% of inspected houses warranted some repair of moisture damage, including ceilings, roofs, joists and window sills. In over 50% of houses inspected there were reports of periods of excessive window condensation.

In 1985 EMR initiated a major study [3] on avoiding moisture problems when retrofitting Canadian single-family houses for energy conservation. The objective was to develop a practical procedure for use by the energy retrofit contractor to predict, for a specific house in a particular location, the extent of energy retrofit that could be implemented without causing significant house performance problems associated with the condensation of water vapour on interior surfaces, or within walls or roof spaces. If a house had insufficient margin for retrofit, or if it were already moisture-troubled, the procedure was required to predict the nature and extent of remedial or preventative measures to avoid the problems. The result was a "Moisture Assessment Prescriptive Procedure" or MAPP.

The approach employed in MAPP is based on the premise that condensation problems in houses can be largely avoided if the average house humidity in January does not exceed a "critical" value corresponding to condensation near the lower edge of double glazed windows, at the average January outdoor air temperature and wind velocity for the location; and preferably does not exceed a "cautionary" value corresponding to condensation near the lower edge at the January daily minimum temperature and average wind velocity. An over-riding requirement is to avoid major air leaks into the envelope spaces, or conditions of moisture entrapment in the envelope. Surface temperatures of windows corresponding to these two conditions were calculated for selected climate conditions, and the relative humidities at 21°C for these two dewpoint temperatures determined. The MAPP then provides a method for estimating average January inside relative humidity. It involves prediction of average January air leakage rates, based on house equivalent leakage area, and prediction of average moisture source strengths, based on occupant living habits and basement moisture conditions. The procedure also includes estimating the increase in R.H. due to various retrofit measures, and/or the reduction in R.H. due to the application of moisture remedial measures. This involves the prediction of the effect on house equivalent leakage area of various energy retrofit measures, based largely on earlier EMR studies [4]. In developing the MAPP, data was collected on moisture-troubled houses in St. John's, Toronto, Ottawa, Winnipeg and Vancouver, in order to provide some support for the premises on which the procedure is based.

Following development of the MAPP, EMR commissioned a field study to assess the validity of the procedure [5]. Data were collected for about 20 houses in each of four regions, represented by Vancouver, Winnipeg, Toronto and Ottawa, and Halifax. A relatively high proportion of the estimated indoor values of R.H., based on the MAPP, were within 10% of the measured values. Some fine-tuning of the procedures was suggested to further improve agreement. The incidence of moisture problems in attics and walls of the trial houses was insufficient to confirm correlation with the MAPP reference humidities.

EMR also supported the development of a procedure for determining supplementary mechanical ventilation requirements for indoor air quality, following air sealing. This was initially in support of the CGSB Working Group on ventilation requirements after retrofit air sealing. It involved support of work at NRC to establish the suitability of different mathematical models for predicting house air leakage rates, based on house equivalent leakage area and weather data [6] (this has relevance to the MAPP, as it involves prediction of house air leakage rates). Subsequently EMR funded the development of a "Ventilation Assessment Prescriptive Procedure", or VAPP, to establish ventilation requirements after air sealing retrofit.

EMR supported the development of a number of training courses by the industries involved with energy retrofit [7], [8], [9]. These courses were based on the "house as a system" concept (articulated by CMHC), and took account of the inter-relationships between the performance of the various sub-systems. Thus all involved a moisture assessment component. One [7] involved application of the complete MAPP and VAPP.

The R-2000 program was EMR's major initiative on energy efficient new house construction in the 1980's. It built on the technology embodied in the 1977 Saskatchewan Conservation House [10] (but without the active solar collectors). That demonstration house incorporated very high insulation levels for the period and a well sealed air-vapour barrier of polyethylene. The house air leakage at 50 Pa was 1.3 ach, about $^1/_3$ that of conventional homes. It also incorporated an air-to-air heat exchanger to provide continuous mechanical ventilation with reduced heating energy cost.

In 1980, the Saskatchewan Government and EMR (through an Enerdemo grant) supported the Energy Showcase Project in Saskatchewan. This was a project of 14 houses that took the concepts of the Conservation House, and others, and applied them in a construction project. One of the documents [11] coming out of this experience describes the requirements for achieving a tight air barrier in highly insulated wood frame envelope systems. It was sponsored by the Saskatchewan Provincial Council of HUDAC and the Government of Saskatchewan. A 4th edition was published by EMR in 1983.

The R-2000 program was announced in 1980. The technology was based initially on experience with the Showcase project. A technical advisory committee was formed that included CHBA, CMHC, NRC, and SRC. Practice guidelines were developed under guidance of the committee, with technical expertise provided by NRC and SRC based on the Saskatchewan experience. The technical strategies related to moisture control were:

- provide a good air barrier;
- use mechanical ventilation to control indoor humidity (and air quality);
- employ good building practice to avoid thermal bridges; and
- control basement moisture source with polyethylene under slabs.

Sealed polyethylene was used initially as a combined air and vapour barrier. The concept of moisture control incorporated, however, the notion of separate air leakage and vapour retarder functions. Houses using sealed polyethylene have been shown to maintain their airtightness over time. An airtight drywall demonstration in Edmonton was funded by EMR, under an ERDA agreement, while CMHC funded a similar demonstration in a project house in Ottawa. Fiberglas Canada funded a house demonstration of fiber glass sheathing with spun-bonded olefin air barrier, with EMR support for the performance testing.

Delivery of the R-2000 program was undertaken by CHBA in 1985, with EMR support. There were rigorous performance standards and a rigorous training program for participating builders. There was mandatory inspection and testing of completed houses. This included airtightness testing to ensure that the houses did not exceed the maximum allowable leakage rate of 1.5 ach at 50 Pa, and determination of the ventilation rates provided.

The program incorporated an extensive performance monitoring phase involving some 300 houses, which included measurements of indoor humidity and other air quality aspects. There was extensive research and development work to resolve technical issues and to provide the necessary technical support. This has included support for the development of a number of standards related to moisture issues [12], [13], [14], [15]. Support has also been provided to HRAI for the development of a design and installation manual for residential mechanical ventilation systems [16], and training courses. Early work on polyethylene degradation was carried out at ORTECH.

The Flair Homes Energy Demo/CHBA Flair Mark XIV project was initiated in 1985 [17]. This involved 20 project houses in Winnipeg. The objective was to demonstrate and evaluate the performance of low energy building envelope systems incorporating different air barrier arrangements, and of various types of mechanical systems (with an emphasis on ventilation), as well as to transfer the knowledge gained to the home building industry. The houses were completed in the spring of 1986. The project was supported by EMR and administered by CHBA. It was designated the Mark XIV project because it incorporated a number of research priorities identified by the Technical Research Committee of CHBA. Performance monitoring continued through to the spring of 1989. This included airtightness changes with time, ventilation performance and usage patterns, and moisture content changes in framing lumber. All wall systems came to acceptable moisture levels and remained that way. No moisture problems were encountered.

While the number of houses built under the R-2000 program is not large, it has had a significant impact on new house construction practice. A core of mainstream builders, prepared to participate, were identified by CHBA. Some 4000 builders were trained in the new practice [18]. A number of the R-2000 concepts have been adopted by the industry and are increasingly embodied in codes and standards. The program demonstrated the feasibility of tight envelope construction and reliable mechanical ventilation systems. It also showed that energy-efficient houses could be built so as to avoid problems of moisture condensation and indoor air quality.

APPENDIX C
MOISTURE RELATED WORK AT NRC

1975 - 1991

Appendix C

Moisture Related Work at NRC - 1975 - 1991

The Division of Building Research (now Institute for Research in Construction) of the National Research Council has a history of moisture related work since its inception in 1947 (see the background section of this report). Work on the performance of insulated flat roof construction, begun in the late 1960's, continued throughout this period at the Prairie Regional Station in Saskatoon [1] to [12]. That program has provided the principal source of information in Canada, on moisture related aspects of flat roofs. No attempt will be made here to review it.

The HUDAC Mark XI Project was initiated in 1977, and located in Ottawa [13]. It consisted of four 2 storey houses with similar floor plans. One had conventional wood frame envelope construction for the period, with R-12 insulation in 2 X 4 stud walls, R-20 ceiling insulation and R-7 insulation on basement walls. The other three had upgraded thermal insulation and air vapour barrier. 2 X 4 studs had 2 X 2 strapping on the inside with 4 mil polyethylene between. Electrical services were contained in the furred space so as not to break the polyethylene. Continuity of the air vapour barrier was maintained at the floor-foundation, second-floor wall and wall-ceiling truss details, as well as at intersections of interior partition walls with exterior walls and ceiling. Nominal insulation values were R-20 for the walls and R-32 for ceilings.

Energy performance of the envelopes and heating systems was the primary interest. However, the moisture performance of the envelopes was monitored and found to be satisfactory. Some observations were also made of moisture transfer from the basement floor slab. The notion was investigated of predicting winter time air change rates from measured rates of evaporation of water required to maintain relative humidity levels. A similar approach was used subsequently in CMHC studies to predict house moisture source strengths from measured air leakage rates.

Extensive measurements of air change rates were made, leading to the development of a model for predicting natural air change rates for single family houses from known values of equivalent leakage area and weather data [14]. The method also accounted for the effects of mechanical ventilation and furnace flues. The validity of the method was confirmed in later studies supported by EMR [15].

The Mark XI project provided another example of the house airtightness that could be achieved with polyethylene air vapour barriers in wood frame construction - when care was exercised in construction detailing and membrane application. An alternate method of air sealing was also proposed [16], employing the interior dry wall combined with adjacent framing and flooring materials and appropriate sealants and gaskets. The system was further developed [17] and performance studies subsequently carried out by CMHC and EMR. Air sealing techniques were also evaluated in the laboratory [18], [19].

A number of building practice documents and building science seminars involving moisture performance were produced in this period; references [20], [21] and [22] are examples. A major book on building science fundamentals, including moisture considerations, widely used as a reference document, was published [23]. Work was carried out in the preparation of a document on Measures for Energy Efficiency in Northern Housing, under EMR sponsorship, but was not completed. Similarly, work was carried out on drafting a document for CMHC, on northern construction practice, in association with CMHC and the Department of Indian and Northern Affairs. It is not yet completed. Currently a major contribution is being made to the preparation of an ASTM Manual on Moisture in Buildings [24], [25], [26].

Studies were carried out in a test hut facility under CMHC sponsorship, to determine the moisture performance of insulated wood frame walls with controlled air exfiltration [29]; further information is given in Appendix A. An analysis was also made of the relative effect of different air flow mechanisms on moisture transfer into building envelopes [28]. It was concluded that only air interchange by convection between indoors and the envelope cavity, and air flow through the envelope under an overall pressure difference, have the potential to transfer large amounts of moisture into the cavity. Outdoor air flow through the cavity has a strong drying potential, which is reduced in regions that are very cold or have a high ambient humidity ratio. Pumping action, due to wind forces and/or due to ambient temperature changes, has a low moisture transfer potential.

Extensive studies have been carried out [29] to [47], and are continuing, on the hygrothermal behaviour of building materials and components. The overall objectives are:

- to develop experimental and analytical tools to assist researchers to evaluate the hygrothermal behaviour; and
- to develop design guidelines for building envelopes free of moisture-related performance problems.

Work has been carried out cooperatively with a group of researchers from the Technical Research Centre of Finland (VTT), over the past two years, with the following specific objectives:

- to develop experimental capabilities to determine moisture transport properties of building materials; and
- to investigate the applicability of a two dimensional computer programme developed at VTT for hygrothermal analysis of residential buildings.

NRC has developed gamma-ray equipment for the determination of moisture distributions in building materials. The materials investigated to date include: eastern white pine; spruce; wood fibre board; gypsum board; plus phenolic, glass and cellulose fibre insulations. Transient moisture distributions in test specimens of these materials were determined at various stages of the transport processes. The duration of the experiment varied from a few hours (gypsum) to a few weeks (spruce and pine). The data were analyzed for deriving total moisture diffusivity of the building materials. Two different techniques were used in the analysis: Boltzmann transformation and optimization methods.

Except for cellulose and glass fibre insulation, the analyses resulted in acceptable sets of values for respective total moisture diffusivities as a function of moisture concentration. To determine the moisture transport characteristics of glass fibre and cellulose insulations, a number of other experiments were carried out. These include: drainage; evaporation of fully saturated specimens; and moisture movement in the presence of a thermal gradient.

The analyses of these data for glass fiber resulted in a consistent set of values for properties such as vapour diffusivity, hydraulic conductivity and suction pressure curve. The development of an experimental procedure for the determination of "thermal moisture diffusivity" is also in progress.

The computer model TCCC2D, developed at VTT, was used in several calculations where typical Canadian residential walls were investigated. In particular, the effect of exfiltration of indoor air through wall cavities was analyzed. Exposure of the wall to Canadian weather at three different locations (viz. Ottawa, Winnipeg and Vancouver) for one year were simulated. These simulations resulted in several interesting pieces of information. The difference in the behaviour of the same wall assembly, but in three different locations in Canada, indicates the need for different design guidelines for the three regions.

APPENDIX D

MOISTURE RELATED WORK AT FORINTEK CANADA CORPORATION

1975 - 1991

Moisture Related Work at Forintek Canada Corporation 1975 - 1991

Forintek Canada Corp. is a private non-profit organization, supported by industry and the federal and provincial governments, established to carry out research and development on wood products. It evolved from the privatization of the federal Forest Products Laboratory. In recent years, Forintek has participated in activities of various Canadian committees concerned with moisture control in wood frame construction, and has carried out a number of studies with special relevance to wood-based materials. A study tour of Norway and Sweden in 1983 [1], in association with the U.S. Forest Products Laboratory, provided useful background on their problems and practices. Included in problems noted were cupping of hard-board siding when installed against impermeable insulation, and condensation in crawl spaces in warmer spring weather due to the cooling effect of the ground.

Monitoring of the moisture content of wood framing in two test walls [2], exposed to outdoor conditions on the exterior side and to conditions of 23°C and 50% on the interior side, led to tentative conclusions about the importance of the airtightness of the sheathing membrane. Wall 1 had standard sheathing paper over wafer board, with two lap joints of 100 mm, and horizontal hardboard, lapped siding installed on vertical strapping. Wall 2 was similar, except that SBPO sheathing membrane, with only one lap joint of 305 mm width, was used, and the hardboard siding was nailed directly to the studs without strapping. Both walls incorporated a stub floor-to-wall intersection and an electric outlet, which penetrated the interior polyethylene air vapour barrier.

It was observed that moisture content increases at various locations in the wood framing were higher in Wall 1 than in Wall 2 during the winter period. It was assumed that the moisture was generally of interior origin, even though the walls were likely to have experienced infiltration much of the time. It was concluded that the differences in moisture behavior were likely due to lower air leakage through the joints in the sheathing membrane of Wall 2.

An analysis of moisture problems in wood frame walls [3] led to some conclusions on recommended research, largely relating to wall airtightness and how it is influenced by factors associated with the characteristics and assembly of wood-based products.

Broad objectives were proposed involving:

- the effects of framing moisture content on the airtightness of various sheathing materials and determination of the equivalent leakage areas of components;
- determination of the effect of bulk insulations on the airtightness of wall cavities; and
- modeling moisture accumulation in walls as affected by construction and environment.

A study of solutions to the problem of truss uplift [4] led also to some suggestions on how to ensure airtightness at interior partitions when floating the gypsum board in its attachment to walls.

An extensive series of measurements were made to determine the water vapour permeance and permeability of waferboard of several thickness obtained from 6 mills [5]. The wet-cup method was used for most of the tests, while a few specimens from one mill were also tested using the dry-cup and a variation on the inverted wet-cup. It was recommended that wet-cup results be used for modeling studies. The dry-cup performance of 11 mm waferboard is in the range of the upper limit normally associated with a vapour barrier. The wet-up permeance is generally two or more times the dry-cup value.

A study was carried out, in association with NRC, on the airtightness of two wood-frame walls insulated with foamed-in-place polyurethane [6]. One wall used 11.1 mm waferboard sheathing, the other 25 mm Type 1 expanded polystyrene insulating sheathing. Both types of sheathing had three vertical joints in the 3m width. Air leakage measurements were made at 75 Pa, following application of pressure differences up to 1000 Pa, at intervals over a period of three months, in order to determine the rate of drying of the framing and the effect of any shrinkage on leakage rates. The airtightness of both walls was relatively high, but the waferboard wall had approximately one third the leakage of the polystyrene sheathed wall. There was relatively little change in leakage as the moisture content of the framing changed, from initial values in the 20% to 30% range, to final values. Both walls dried at similar rates, to the 14% to 16% range. It was concluded that, in practice, it would be prudent to allow lumber to dry to reasonable levels before application of the polyurethane insulation. In retrospect, it would be interesting to know the leakage characteristics of the sheathing joints prior to application of the insulation.

A series of tests were carried out to determine the air leakage characteristics of one type of hardboard horizontal lapped siding [7], to provide data for computer simulation of wall drying. The rate of drying of the outer layers of walls is influenced by both their water vapour permeance and air leakiness. Leakage at the over-lap, in the siding used, depended upon the stand-off provided by the nails and the tightness at a spline which supported each course on the course below. The spline incorporated vent holes to increase the leakage at this detail. It was found that both round-headed and flat-headed nails could provide the necessary standoff, although the round-headed nails were more prone to over-driving. The vent holes did not contribute significantly to leakage, compared to imperfections in the contact of the spline with the course below. The air leakage rates per meter of joint length for this siding, at 75 Pa pressure difference, averaged 0.52 l/s. This was much lower than values obtained by others for various siding types.

A study was carried out on the effect of drying of wood framing on the air leakage of joints in wall framing [8]. It was concluded that there could be large increases in joint leakiness when lumber dries. Nail popping is related to embedment length. There is a large variability in lumber shrinkage related to growth ring orientation and proximity to pith.

More recently, twenty four full-sized test walls, with two joint configurations in the exterior panel sheathing, have been built and tested for air leakage [9]. The effect on air leakage of drying of framing, from the green state to 19% moisture content, has been determined. An additional six full-sized walls were tested to determine the influence of lumber shrinkage on air leakage around the wall-to-floor connections in platform construction. The results have not yet been reported.

A national questionnaire survey of home owners was carried out to assess the performance of preserved wood foundations in service. A generally high level of satisfaction was expressed. There was a small incidence of musty smells and water leakage. It was concluded that better attention to recommended practices, particularly site drainage of water, is needed.

The levels of moisture built into walls in actual construction has been the subject of a national study, sponsored by CMHC [10]. The moisture content of over 6000 studs, in 515 houses across the country, was obtained. It was measured just before the installation of insulation and vapour retarder. It was determined that mostly 38 x 140 mm studs were being used for wall construction in most regions. Only in Toronto and Vancouver were 38 x 89 mm the predominant choice. Builders in the Prairie regions used mostly S-DRY lumber, while those in the Atlantic region used mostly S-GRN. While the S-DRY was often drier than the 19% limit in the NBC, a significant percentage had higher moisture contents, some over the 30% fibre saturation value. 82% of S-GRN sill plates had moisture contents greater than 19%; 35% had moisture contents greater than 30%. Drying during construction was often insufficient, and 77% of builders reported problems with drywall nail popping and cracking. It was recommended that builders pay more attention to the moisture in their lumber, and that the lumber industry use better quality control in the processing of S-DRY lumber.

Recently, Forintek assembled a task force to consider issues, for the wood products industry, with respect to the moisture performance of building systems [11]. While there is relatively frequent individual and co-ordinated exchange between members of the research community, there is generally inadequate exchange between researchers and the wood products industry. The task group was intended to provide a forum for this interchange. The task group reviewed recent research work of CMHC, NRC and Forintek. Recommendations for research included:

- determination of the best means by which the management of moisture within the building framing can be accomplished, for example:
  - demonstration of different construction techniques in cooperation with CHBA;
  - study the economics of better construction techniques with S-DRY and S-GRN lumber; and
  - study the benefits of using S-DRY for wall plates with better building practices vs using treated bottom plates.
- determination of the extent and severity of dry wall problems associated with different levels of framing moisture content, (m/c) for example:
  - S-GRN studs;
  - studs at 19% m/c; and
  - studs at 15% m/c.

APPENDIX E

MOISTURE RELATED WORK AT THE UNIVERSITY OF TORONTO
1975 - 1991

Moisture Related Work at the University of Toronto

The Centre for Building Science, in the Faculty of Applied Science and Engineering, University of Toronto, has been involved in moisture-related studies for over a decade.

Building on a study of Scandinavian research and practice in heat and moisture control in basements [1], a major cross-Canada research and development program was carried out under the sponsorship of HUDAC and CMHC. Some sixteen demonstration basements were constructed by builders across the country, with different insulations (supplied by four manufacturers) applied to the outside of the foundation walls. Performance monitoring was under the direction of the University of Toronto. The results of the study were embodied in a building practice document published by HUDAC [2]. The document indicates the advantages of external insulation, how much insulation and what types are suitable, and procedures for its installation.

A comprehensive document on insulation of existing basements [3] was produced to provide guidance to those making retrofit decisions. It deals in an understandable way with the relevant physics of heat and moisture, and the durability implications, for the range of basement construction types likely to be encountered. Issues of interior vs exterior insulation, insulation and moisture control details, and energy economics are addressed.

A paper presented in 1982 [4] summarizes the technical issues involved in controlling heat losses and moisture in basement walls. The desirability of an appropriate drainage layer on the exterior to maintain atmospheric pressure (and avoid hydrostatic pressures) at that location is stressed. The merits of external insulation in providing advantageous hygrothermal conditions for moisture control are emphasized. The use of glass fibre insulation in addressing these objectives is discussed, based on Scandinavian experience and research at the University of Toronto [5]. Fibrous insulation materials can provide a self-filtering, capillary-breaking and free-draining layer. The moisture content of the insulation generally remains below 1% by weight, so that the material maintains its thermal resistance, and there is very little penetration of silt into the exterior surface layer in contact with the soil. The external surface of the concrete wall generally remains above soil temperature, so that the relative humidity at the surface is below 100% and the moisture content of the concrete is correspondingly reduced.

The mechanism of drainage in glass fibre insulation is dealt with in depth in another paper [6]. Here it is shown that, as long as the predominant fibre orientation is in the plane of the board, water introduced into a vertically positioned board remains in the plane into which it is introduced. There is no measurable capillary movement in the direction normal to the board and, if the glass fibre diameter distribution and packing density are known, the Young and LaPlace equation can be used to predict capillary rise parallel to the plane of the board. In the boards tested this rise was not sufficient to be of concern in foundation applications.

Rock wool insulation was included in some tests with insulation in contact with saturated soil. Water in the soil did not penetrate the insulation, including rock wool, by more than a couple of millimeters, and flow rates on the insulation board faces were more than adequate for soil drainage purposes. However, when water was introduced into the top of the rock wool board, the water did not remain in the plane of its introduction, but moved normal to the plane of the board in all directions, to wet a conical volume below the point of entry. The rock wool had short, fine, closely packed fibres with no discernible anisotropy in fibre orientation and there appeared to be significant capillarity in all directions. Lack of moisture penetration of the rock wool in the soil drainage tests is attributed to treatment of the board surface with a water repellent. Lack of normal-to-the-board capillarity, as evidenced in the glass fibre specimens, would appear to be a desirable characteristic.

One of the concerns raised in connection with insulating of basements, particularly with interior insulation, was the possibility of increased risk of adfreezing and damage due to frost heaving of adjacent soil. Adfreezing is the mechanism by which frost-heaving displacements are transmitted to the basement wall by a combination of friction and ice bonding of the soil to the basement wall. Interior insulation lowers the temperature of the basement wall and the adjacent soil, resulting in temperatures below freezing at the soil-basement interface in many regions of Canada. Field investigations did not substantiate any cases of frost problems induced by thermal insulation of heated basements [7]. On the other hand, frost damage to foundation walls is known to occur in unheated basements and in garages.

Research [8] at the University of Toronto was carried out to develop a better understanding of the physics involved, to explain the apparent lack of field problems. It is hypothesized that the adfreezing bond strength is affected by the direction of soil moisture movement in response to thermal gradients [9]. It is postulated that the direction of moisture movement in winter is away from the basement wall, towards the soil, even in insulated walls, and that this reduces the adfreezing bond strength. Even when freezing occurs, there is vapour movement from the ice crystals in contact with the wall, causing progressive desiccation, and weakening the bond. In unheated basements, moisture moves in the direction of soil to wall, increasing the adfreezing bond strength.

Staff of the Centre for Building Science participated in the CMHC-sponsored study of moisture induced problems in NHA housing [10] (see Appendix A). A number of modifications were proposed to overcome the types of problems observed, particularly in Atlantic Canada. One of these was the use of insulating sheathings [11]. A laboratory study [12] of glass-fibre batt insulated walls with polystyrene and glass fibre insulating sheathing, in which moist indoor air (20°C and 50% R.H.) was introduced into each stud cavity at a fixed rate of 0.18 L/S, indicated that moisture accumulation in the cavity and sheathing was dependent on both outdoor temperature and the vapour permeability characteristics of the sheathing. With an outdoor temperature of -5°C the interior surface of the polystyrene was above the dewpoint temperature of the indoor air and there was negligible moisture accumulation, amounting to less than 2% of the total introduced. (Author's note: The glass fibre sheathing was not tested under this condition, but rather more accumulation could have been expected, particularly in specimens where the SBPO facing was on the exterior.) With an outdoor temperature of -20°C, there was an increase in accumulation in both cavity insulation and polystyrene sheathing, amounting to 14 to 18% of the total introduced. Some specimens had two and four slots, 3 mm wide, cut through the polystyrene sheathing across the full width of the studs. Moisture accumulation was somewhat higher in these walls than those without slots, partly because of frost accumulation in the slots. Thus, under these conditions the slots had no beneficial effect. Most of the moisture associated with the polystyrene sheathing was on the surface, at the interface with the cavity insulation.

Specimens with glass fibre sheathing, where the SBPO membrane facing was on the exterior, showed the highest moisture accumulation in the sheathing, and the lowest in the cavity insulation (which was negligible). In this case the condensing surface (the

SBPO facing) was at the lowest temperature. Moisture accumulation amounted to about 40% of the total introduced. The specimen in which the SBPO facing was on the inside had a much lower accumulation (about the same as the polystyrene without slots), but the accumulation in the cavity insulation was somewhat higher than with the other glass fibre sheathing (although less than with the polystyrene sheathings). The authors conclude that glass fibre sheathing with the SBPO membrane facing the weather side is advantageous when moisture sensitive sidings are used, as the sheathing is capable of harmlessly storing moisture under adverse exfiltration conditions, which can be dried out or drained away under more favourable conditions.

Handegord (Prediction of the Moisture Performance of Walls, ASHRAE Transactions, Vol. 91, Pt. 2, 1985) sees an advantage to locating the condensing plane at the inner surface of insulating sheathings, particularly if there is provision for drainage of condensed moisture at this location.

In the CMHC moisture problem survey (see Appendix A), mould and mildew on interior surfaces, particularly at exterior corners, was a common occurrence at the Atlantic Provinces. It was speculated that wind pressure was causing air to flow in and out at the windward and leeward sides of corners, respectively, through flaws in the sheathing assembly, thus decreasing the effectiveness of the insulation and lowering inside surface temperatures. A full scale laboratory study [13] verified that wind could lead to an additional temperature drop of up to 7°C beyond that due to other effects found in an exterior corner. The study demonstrated the effectiveness of an externally located air barrier in preventing air leakage at corners.

Another study dealt with laboratory methods of evaluating air barrier systems [14]. A method is proposed for testing the leakage of joints in enclosure elements using two identical specimens placed back-to-back. The symmetry thus provided eliminates, for practical purposes, all joints not found in the actual application.

Ventilation is one of the techniques for limiting the levels of indoor relative humidity in winter. Exhaust air systems, for this purpose and for capture of indoor air pollutants at source, are common. A relevant study carried out by the Centre for Building Science, under the sponsorship of EMR and the Ontario Ministry of Energy, involved assessment of the venting performance of naturally aspirated gas-fired furnaces and hot water heaters in the field [15]. A blower-door, house-leakage test rig was used to depressurize the house until venting failure occurred. It was concluded that venting failure can occur with a cold chimney in mild weather, when combinations of typical house exhaust devices are in operation, depending upon house airtightness. However, with the population of houses tested, the probability of draft failure was quite low. Increasing house tightness and larger capacity exhaust fans would increase the probability.

To demonstrate the advantages of locating the air barrier on the cold side of the insulation (easy installation and prevention of wind cooling of wall assemblies through flaws in the sheathing assembly), an experimental house was built [16] [17] utilizing glass fibre sheathing with the SPBO membrane on its exterior surface. Joints in the sheathing were sealed with special tape. The house had an airtightness of 1.56 ach at 50 Pa prior to installation of siding, approximating the minimum tightness requirement of R-2000 houses. Calculations indicate that about 0.9 ach of this was associated with wall leakage. It was concluded that the house could be operated at a negative pressure of about 10 Pa to provide for the continuous ventilation requirements of the house, resulting in a "dynamic wall" in which air flowing in through the wall is warmed by heat flowing by conduction from inside to outside, under heating conditions.

It is theorized that, at the optimum air flow rate, the temperature of the air leaving the inner surface of the glass fibre cavity insulation is at the same temperature as the inner surface of the insulation (or outer surface of the wall board) under no-airflow conditions. That is, at optimum flow, the inside surface temperatures are unaffected. Optimum air flow is said to occur under the condition when the heat transferred to the air, in its passage through the insulation, is equal to the portion of overall heat transfer through the insulation due to conduction in the air component of the insulation (under still air conditions). This results in a simple equation for optimum flow rate per unit area that depends only on the conductivity of still air, its density and specific heat, and the thickness of the insulation. Only thickness is a variable, and optimum flow rate varies inversely with thickness.

For the walls of the experimental building, the optimum flow rate corresponded to a house air change rate of 0.26. The corresponding energy saving for heating the air was computed to be 2240 kwh with 4350°C days for heating.

In the experimental house, air was withdrawn from the wall cavities through a 25 mm hole through the wall board near the bottom of each cavity. Surface temperature observations did not reveal any distortions of inside wall surface temperatures resulting from the flow path.

One of the advantages claimed for the dynamic wall is elimination of any potential for concealed condensation. The flow of air through the wall would also promote drying of any construction moisture.

The dynamic wall also offers potential as a solar collector [18]. Work on the experimental house has shown that it has the ability to capture a significant portion of solar radiation incident on it. It is postulated that the reduction in the heat demand of the house due to such walls can be equivalent to increasing the thickness of batt insulation by some 190 mm or an increase in R-value of about 22 (RSI of 3.95). This is achieved with 2 x 4 in. studs, which translates into savings associated with smaller overall house dimensions and lot size, or alternatively, allows a larger indoor floor area for the same lot size.

Utilization of the incident solar radiation requires storage of heat during periods when heat gains exceed heating demands, to be utilized when the imbalance is reversed. Heating of domestic hot water, and for thermal storage under basement slabs are suggested as possible ways of balancing supply and demand. In this context the exterior walls are seen as part of the heat recovery ventilating system, with an added capacity for capturing solar energy.

APPENDIX F

OTHER MOISTURE RELATED WORK
1975 - 1991

Other Moisture-Related Work

During the period 1975 - 1991 a number of other Canadian organizations, in addition to the five referred to in Appendices A to E, carried out work related to moisture problems in wood-frame residential construction. These included some Universities and Provincial government agencies, as well as some manufacturers. Some of the work of CHBA has been referred to in Appendices A, B and C. It is not possible here to provide an exhaustive report on all of this. To broaden the record, however, this Appendix contains information on work at the Alberta Home Research Facility, taken from a paper, Moisture Research in North America, assembled by Dr. M.T. Bomberg of NRC. It also contains a record of some of the work carried out by the siding industry on siding moisture problems, prepared by Mr. John H. McKenzie, P.Eng., who was directly involved.

The Alberta Home Heating Research Facility

Research activities on moisture problems in residential buildings involves both a field monitoring program and modeling. The two areas of current interest are moisture deposition in exterior walls and attics during winter. Field monitoring is underway at Alberta Home Heating Research Facility (AHHRF), which is a test site near Edmonton consisting of six, single storey houses with full basements, arranged in an east-west row. Two of the houses are humidified during winter and moisture deposition in the walls and attic, together with ventilation rates and forced convective air flows through each zone, are monitored continuously. The objective of this phase is to collect a large database on convective air flows (dominant moisture transport mechanism) and moisture deposition. Concurrently, model development is underway to predict moisture deposition in walls and attics, with the database used for model validation. The wall model is based on heat and mass transfer across a cavity filled with porous insulation, with forced convective air flow in a vertical direction. Condensation (or sublimation) occurs on the cold exterior sheathing and the amount and distribution of moisture is predicted by the model. The attic moisture model consists of two sub-models; one is a two-zone, indoor-attic air ventilation model, based on air flow mass balances in each zone. The other is an existing thermal-moisture balance model, which uses the attic ventilation rate and indoor-attic exchange rate as input.

Future work will involve using these models to identify construction details (such as size and placement of passive roof vents) and ventilation strategies to eliminate or control moisture in houses, under the varying winter conditions experienced in Canada. It is planned to field test some of the ideas that have been identified, by model calculations at AHHRF, during the next few winter seasons.

Some Moisture Related Work on Sidings Conducted by Private Industry *

Manufacturers of siding and sheathing products were among the first to become involved in the problem of wet walls in Atlantic Canada; their research led quickly to the involvement of government and public institutions. In particular, Masonite Canada (later renamed "Canexel") contributed considerable R & D effort and analysis, based on some 750 field inspections of siding on wet walls, primarily in the Atlantic region. The following describes some of this work.

1. Visual Indications

In 1976, Masonite started to see a significant increase in moisture related problems on their hardboard sidings in the Atlantic provinces.

In 1978-79 there were reports, from CMHC in Newfoundland, of an eruption of "buckling" problems. Investigation, however, showed that the basic problem was more paint peeling and/or rotting of the siding, with occasional coincidental buckling.[1]

As a result of this new and unexpected development, Masonite started a crash program to identify the problem, to do necessary R & D work and recommend a practical solution. Two in-house task forces visited many of the complaint houses

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* From notes compiled by Mr. John McKenzie

1 The former is caused by sustained wetting by liquid water while buckling is due to excessive hygroscopic expansion of the cellulose fibres. Liquid water also causes fibre expansion, however it appears that the water acts as a plasticizer and usually allows relief of internal stresses built up by the fibre expansion, thus preventing buckling.

Canexel in 1985-86 developed and installed equipment to increase the moisture content of their siding, as shipped, and has thus largely eliminated buckling problems.

throughout the Atlantic region and collected detailed reports on each. Scanada was retained to provide guidance and expertise.

As a back-drop to the Newfoundland situation, since about 1970 it had been the custom in Quebec[2], ***only***, to install Colorlok siding on strapping (or furring - "forrins" in Quebec). There was some increase in wet wall problems in this province, in the late 70's in the Saguenay and Gaspé regions, but they were minor compared with Newfoundland. Also, Masonite's installation instructions since about 1962 had specified strapping for all re-sides (based on the premise that many older houses had poor or non-existent air-vapour barriers) and the Company rarely if ever got complaints on these jobs when strapping had been used.[3]

Against this background, use of strapping was the obvious solution, at least in the short term, until a more detailed analysis was made. And apart from prior experience, it seemed obvious that in a general sense, "ventilation" of a wall (from convection and wind effects) would be beneficial in the same manner as it was for attics.

To further prove out this system, Masonite set up a number of tests:

1. Eight electrically-heated houses in Newfoundland were built with the siding installed on strapping (the builders were specially selected and instructed). These sites were last inspected in the mid 80's and there were no signs of moisture problems.

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2 And remains so - 100% in some areas, *irrespective* of the type of siding.

3 Older homes also were more likely to have dirt floors in the basement and it was well known from experience that this condition was often associated with very serious wall rotting problems.

2. A test hut was built in St. John's, on a cliff facing the direction of severe storms. Strapping was used and Plexiglas sheathing allowed observation of the back of the siding. No rain penetrated the siding, even during an unusually severe storm.

3. A mock wall was tested at Warnock Hersey for rain penetration and again the results were negative.

4. Simulated wall sections were put in a climatic chamber in Masonite Corp's lab in Chicago, to evaluate the rate of frost build-up in the cavity with various strapping configurations. In particular, there was interest in finding out whether a perforated starter strip, on solid horizontal strapping at the bottom, would provide sufficient ventilation. Such a set-up would have simplified construction compared with the "normal" fully-open slot, covered with a bug screen.

The assessment of the results led to the conclusion that:

- Furring strips did indeed minimize frost build-up in the cavity behind the siding;
- It was necessary to have a relatively large open area at the bottom of the slot and essential to have a fully open top; and,
- A shallow slot was as effective as a deeper one, i.e. $^1/_4$" was as good as $^3/_4$".

By and large these conclusions confirmed common sense and tallied with field experience.

It was the writer's understanding that these results were made available to others. Masonite personnel were, therefore, surprised to learn later that test hut research was being done with the top of the slot closed off.

As a result of this experience, Masonite, in conjunction with the CSSRMA[4], prevailed upon CMHC to specify strapping for all horizontal lap sidings in Newfoundland. Before this could be extended to all areas at risk, i.e. Atlantic Canada, CMHC changed the requirement to a "recommendation" and there the matter rests.

2. Further Work

In frequent travels to Newfoundland and the Maritimes, the writer continued to see evidence of wet walls, not only on hardboard but, incidental to the purpose of the trips, on other types of sidings[5]. In conjunction with Scanada, a clearer understanding of the problem developed and a detailed analysis was made of the information collected during the second Masonite Task Force.

This showed fairly conclusively that the problem was due to exfiltration of indoor air in winter, driven primarily by the lee-side wind effect. This was deduced from the close correlation (99.9% significance) between wind direction and wall problems (see reference 6 in Appendix A). Also, the vertical profile of visible moisture damage showed that the problem *decreased* with increasing wall height, i.e. opposite to the buoyancy, or stack effect. There were few cases that might have been attributed to rain penetration[6] and in any case, data from suspect cases was not included in the analysis.

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4 Canadian Siding Soffit and Rain-Goods Manufacturers Association.

5 A collection of 40 to 50 photos was built up as examples of the problem.

6 As the inspections progressed, it became possible to diagnose rain penetration problems on-site, sometimes confirmed by inspection when a wall was stripped. These cases were relatively few and in many instances the moisture troubled areas were in locations that precluded entry of rain,

This conclusion did not seem surprising; at St. Johns, average wind velocities from the westerly direction (which occur about 57% of the time) average about 30 km per hour over the period from October to March. This translates into a pressure difference across easterly walls of about 13 Pa in an exposed location and about 6 Pa in a more protected one[7]. By comparison, buoyancy pressure differences causing exfiltration are not likely to exceed 5 Pa across ceilings of 2-storey houses at an outdoor temperature of 0°C, with lower average pressure differences across the walls.

It was reasoned that exfiltration condensation resulted in in-wall rot, in this region, as spring and summer drying conditions were too weak to dry the interior of the wall and thus prevent the onset of dry-rot[8]. Corroborating this was the fact that, even though water had been seen literally running out from behind siding laps on the prairies (from melting ice, on a warm spring morning), the company ***never*** had exfiltration complaints from this region.

3. Existing Houses at Risk

In advising home-owners about corrective actions ***after*** a problem had developed, Masonite recommended installation of a good quality exhaust fan; preferably a

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e.g. in the middle of a wall well away from any entry points. Often the affected area correlated with obvious potential air leakage paths such as a spine wall or electrical outlet. Gable ends, above the ceiling, **never** suffered from moisture problems.

7 Very moderate, by Newfoundland standards. The figure does not include the pump-up effect from windward side infiltration which can occur if windward walls are more leaky than leeward walls.

8 In cases where walls were opened up, liquid water was sometimes seen glistening on surfaces within the wall, even in the summer months - in one specific case, on July 31.

squirrel-cage type[9] of at least 80 cfm (≈40 L/s) controlled by a dehumidistat or timer. The question of causing back-drafting of furnace flues had to be considered, although this was not thought to be a particular concern in the Atlantic Provinces in the absence of natural gas. It is now recognized that excessive house depressurization can cause flue gas spillage with wood-fired appliances, and even oil-fired ones.

This idea was tested out in a house in Newtown (St. John's) that was experiencing a serious exfiltration problem. The fan was installed in September when the siding moisture was measured at 40% in the troubled area (using a portable hand-held meter). In January the moisture had dropped to 20% and had again decreased to 15% by June. Thus, even over winter and despite being in a known area of exfiltration, use of the fan had effectively dried out the siding.

4. Flued vs Flueless

There has been some question as to whether exfiltration problems are primarily restricted to houses without an active flue. Records of inspections of 241 homes with wet wall problems, made by the writer in the Atlantic Provinces in 1983 and 1984, showed 42% of the total were combustion heated (58% were electric or, occasionally heated by a wood stove with no flue damper). In this group, one third (15% of the total) had no apparent construction defects (such as no air-vapour barrier, dirt floor, etc.). Thus the effect of an active flue (lower RH and lower interior air pressure) was apparently insufficient to counter the wind-induced leakage and/or the indoor moisture load.

Records were also kept of the severity of "tell-tales". These were primarily the stains on the sills of picture windows (and **not** the assessments of the home-

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9 The emphasis on the fan quality was felt to be important as cheap propeller-type fans cannot withstand long-term continuous operation.

owners). While there was a rough correlation between the severity of the stains and the severity of the wall problems, there were many instances where relatively "dry" houses were suffering severe wall rot.

5. Miscellaneous

It was possible to inspect the wall behind the siding in a number of instances and, generally speaking, there was in-wall rot where severe siding rot was apparent. In extreme cases, both sheathing and studs were rotted[10]. As the primary concern was with the siding, no record was kept of the type of sheathing. However, from memory:

- There did not appear to be any great differences in the pattern or severity of siding problems that related to the type of sheathing (primarily lumber, chip-board and asphalt-impregnated fiberboard); and,

- There was little rot in the asphalt-impregnated fiberboard, while chip-board seemed to rot readily. In some instances, rotted sheathing could be dug out with the finger nails.

Despite the overall correlation, in any given instance there was considerable variation between the condition of the siding and that of the sheathing - in one case the sheathing would be rotten, in another there would only be minor staining or mould on the building paper. In was thought that this variation was probably due to the variation in position of the dew point of the exfiltrating air within the wall.

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10 In one memorable but quite exceptional case, on a house with a full dirt floor and nothing but $^1/_8$" panelling on the interior, two walls were so badly rotted that the home-owner had propped the roof up with poles for fear of a total collapse.

Canexel is still producing and selling hardboard siding products across Canada (albeit at a considerably reduced level in Newfoundland) plus a small but increasing export component. Current sales are in the neighbourhood of 50 MMSF per annum, including a substantial amount in the Maritime provinces.

In 1982, in the normal course of technological improvement, changes were made that may have reduced the product's sensitivity to sustained in-wall condensation.

6. Other Sidings

At least until 1982, Masonite sidings may have been unduly sensitive to the ravages of interstitial condensation, although there were some grounds for believing that in the more severe cases, this was fortuitous in that the home-owner was warned before his wall had rotted out. In any case, it was believed that the inherent problem was with the structure - not with the siding per se. There thus seems to be no reason to expect that walls clad with other types of siding are not at risk. And, except for lumber clap-board, any exterior evidence is usually subtle at the best.

As noted in (2) above, Masonite personnel did see (and also heard about) not infrequent wet wall problems with other than hardboard sidings and, in particular, the writer was quite concerned about the wholesale re-siding of old, poorly built, air-leaky houses, e.g. Grand Bank in about 1981. At that time, it was felt that there was a disaster in the making and there has been no reason to change that opinion since. The increasing use of SBPO membrane over sheathing is, however, a more recent positive development and may reduce the risks, *provided that* this membrane is installed with care. The beauty of strapping lies in the fact that it is inherently a fail-safe system, at least for controlling siding moisture conditions.

7. Conclusion

Despite the very considerable research done since about 1980, there has been no change in the mandatory[11] requirements for residential construction specific to the Atlantic provinces, and there is no guarantee that evolutionary improvements in residential construction practice, specific to the Atlantic provinces, have materially reduced the in-wall moisture problems that were seen from 1978 to 1982 - it is likely that these are merely less apparent from the outside.

It would seem that there must be sufficient knowledge now available to provide practical help to builders and home-owners in this region. Merely suggesting "more studies" does a disservice to the people who have already waited twelve or more years and suffered losses in the millions from the ravages of exfiltration rot.

The same reasoning holds true for renovation work. Although there is no regulatory means of reaching this market, the CSSRMA could be strongly advised to specify installation methods to minimize risks associated with air leakage in older houses.

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11 Dissemination of new knowledge is slow when it is merely recommended. However, when translated into a mandatory requirement, the building industry responds rapidly.

APPENDIX G

MOISTURE CONTROL REQUIREMENTS IN THE NATIONAL BUILDING CODE OF CANADA

Moisture Control Requirements in the National Building Code of Canada

Canada's National Building Code was first published in 1941, sponsored jointly by the Department of Finance and the National Research Council. Work on the National Building Code was resumed in 1949 by the National Research Council, under the direction of an Associate Committee, which issued a NBC 1953, and new editions at intervals to this day. Until 1970, the NBC contained some of the provisions for moisture control in residences, while additional provisions were contained in residential standards. These were first published by CMHC and subsequently, beginning in 1958, by the Associate Committee on the National Building Code (ACNBC). The moisture control provisions in Part 9 of the NBC 1970 were essentially the same as those in the residential standards. The residential standards were last issued in 1977.

NBC 1941

There is no specific Part dealing with residential construction in the NBC 1941. Provisions for stud wall construction require that an effective vapour barrier be used between the interior face of the studs and the interior face of the wall whenever the building paper or the sheathing is highly resistant to the transmission of water vapour. It is noted that a vapour barrier is desirable whenever the vapour transfer factor for the building paper/sheathing is less than 2 grams/24 hours · m^2 · mm Hg (3 grains/hour · ft^2. in Hg). A vapour barrier for this purpose is defined as having a vapour transfer factor of not less than 0.5 (0.76 grains/hour · ft^2 · in Hg).

No exterior wall of any habitable room is to have a U-value greater than 0.25 Btu/h. $ft.^2$ °F. The corresponding value for roofs is 0.35. Walls and floors of habitable rooms in basements are to be so insulated that there will be no condensation on interior surfaces during periods of high humidity in summer. There are also general requirements for waterproofing and dampproofing basement floors and walls.

Space between the bottom of floor joists and ground (if not occupied by a basement or cellar) is to be ventilated. The minimum area of openings in the foundation wall is 20 $in.^2$ for each 25 lineal feet of wall. There do not appear to be any requirements for ventilation of roof spaces.

NBC 1953

There is no specific Part dealing with residential construction in the NBC 1953. In Part 4 on design, there is a requirement that consideration be given to condensation control in the design of walls, roofs and floors; where a gradient in water vapour pressure exists within a building assembly, which may cause condensation, a vapour barrier is to be used, installed on the high vapour pressure side of the material providing the major thermal resistance. Treated papers to be used as vapour barriers are to conform to CGSB 9GP3. Where materials having a high resistance to water vapour flow are used on the low vapour pressure side of the major thermal resistance, ventilation or other approved method of equal effectiveness is to be provided (in addition to a vapour barrier) for removing the water vapour which may enter from the high vapour pressure side.

Attic spaces are to be ventilated with openings providing a minimum of 1 $ft.^2$ for each 150 $ft.^2$ of attic space area, with openings placed to provide optimum circulation and air change.

Crawl spaces are to be ventilated with a minimum of 1 ft^2 for each 1000 ft^2 of crawl space area.

Basements are to incorporate drainage around the foundation, below the level of the floor, and waterproofing where conditions warrant. Otherwise, walls are to be dampproofed, with a heavy coat of undiluted hot asphalt, or hot tar (placed over $^1/_2$ in. cement plaster on masonry unit walls).

NBC 1960

Part 9 of the NBC 1960 calls for vapour barrier protection, in accordance with good practice, of insulation that does not effectively limit the passage of water vapour over its entire surface. The Canadian Housing Standards is referenced for good practice.

Foundation walls, floors of basements, slabs on grade, and crawl spaces are to be constructed to resist the passage of water and water vapour in accordance with good practice. Unless otherwise permitted by the authority, all foundation walls and crawl spaces are to be drained.

Ventilation systems are to be designed, constructed and installed in accordance with good practice.

Section 4.7 on Cladding contains general provisions on the control of condensation. Where a building assembly is to be subjected to a gradient in temperature and water vapour pressure, such that condensation will occur within the building assembly:

a) A vapour barrier is to be installed at or near the high water vapour pressure side of the major thermal resistance;
b) If an air space forms part of the assembly, it is to be vented to the cold side; or,
c) Materials on the cold side are to be at least five times as porous to vapour as those on the warmer side.

Where materials are used on the cold side that have a resistance to water vapour transfer equivalent to a vapour barrier:

a) A Type 1 vapour barrier (CGSB 70-GP-1) is to be used;

b) A ventilated air space or other method is to be provided for removing water vapour that is likely to enter or pass through the major thermal resistance.

NBC 1965

Provisions in Part 9 of the NBC 1965 are the same as in the NBC 1960. There is an additional provision for rooms ventilated by mechanical means, specifying a system capable of providing at least 1 a.c.h.

Interestingly, Part 4 of NBC 1965 reflects the then relatively new understanding of the importance of air exfiltration. It calls for a vapour and continuous air barrier on the high vapour pressure side of the major thermal resistance. Any air space on the cold side of the insulation is to be vented to the outside. Materials on the cold side are to be more porous to water vapour than those on the warm side. If they have a resistance to water vapour transfer equivalent to that of a vapour barrier, a vapour barrier is required on the warm side, along with a vented air space on the cold side.

NBC 1970

In the NBC 1970 the requirements in Part 9 and in the Residential Standards are largely the same. There is a subsection specifying insulation:

- to be provided between heated and unheated spaces, and between heated spaces and the exterior, and around the perimeter of concrete slabs-on-grade;
- need not be provided for masonry or concrete basement or cellar walls, including spaces between joists, enclosing unfinished space, or crawl space walls not used as a plenum.

There is also a reference to batt-type insulation with no membrane on either face, requiring that at least one face be installed in full and continuous contact with the cladding, sheathing, etc.

Vapour barrier materials are to conform to CGSB 70-GP-1 (1960). This standard applied to both building papers and polyethylene used as vapour barriers (replacing CGSB 9-GP-3, which was based on building papers only) and referred to Type 1 and Type 2 materials, with maximum permeance of 0.1 and 0.75 perms respectively (5.7 and 43 $ng/s \cdot m^2 \cdot Pa$). Type 1 vapour barriers are to be used where a high resistance to water vapour transfer is required, such as in wall constructions incorporating cladding or sheathing with a low water vapour permeance.

Vapour barriers are to be installed so as to protect the entire wall area, including framing members. Where an interior wall meets an exterior wall or ceiling, the vapour barrier is to cover the area between. Vapour barrier membranes are to be lapped one inch over supporting members, and four inches otherwise. Openings in the vapour barrier around electrical boxes and registers are to be cut so that there is a snug fit.

Attic and roof spaces above an insulated ceiling are to incorporate vents to outside having an area of not less than $^1/_{300}$ of the ceiling area, to be uniformly distributed on opposite sides of the building. In the Residential Standards venting of the roof space is not required if there is a Type 1 vapour barrier over the entire ceiling, applied as a single sheet without openings, except for plumbing vents where openings are to be sealed. This is an implicit acknowledgment of the role of air exfiltration.

Crawl spaces are to be ventilated by natural or mechanical means, with vents for natural ventilation of not less than 1 sq. ft. per 500 sq. ft. of floor area. Ventilation is not required when the crawl space is heated, or vented to the basement.

Where hydrostatic head exists, floors on ground and exterior surfaces of walls below grade are to be waterproofed. Otherwise, foundation walls of spaces below grade are to be dampproofed with a heavy coat of bitumen or other approved material. Unit masonry foundation walls are to be parged before dampproofing. Where separate interior cladding is applied to foundation walls in contact with the soil, or wood members are applied for insulation or finish, interior surfaces are to be dampproofed from basement floor to ground level (but not above), with at least 2 mil polyethylene or two coats of bitumen or equivalent (this was consistent with CBD 13).

Slabs on ground are to be dampproofed unless supported on not less than 5 in. granular fill. Dampproofing located below the slab is to be at least 6 mil polyethylene or 45 lb. roll roofing, lapped 6 inches (trials at DBR/NRC had shown that anything lighter than this was likely to be damaged during placement of concrete). Where a separate floor is located on top of the slab, dampproofing can be provided on the slab surface, using not less than 2 mil polyethylene or two coats of bitumen, or equivalent.

Mechanical ventilation requirements are the same as in NBC 1965.

Part 4 provisions are similar to those in NBC 1965.

NBC 1975

Requirements in Part 9 of the NBC 1975 and in Residential Standards are the same. The requirement for vapour barrier protection at the intersection of interior walls with exterior walls and ceilings is more explicit than in NBC 1970, calling for it to extend between the interior and exterior walls, and over the top of interior walls or beneath the top wall plate. Other requirements are as in the NBC 1970. Part 4 provisions are also the same as in NBC 1970.

NBC 1977

The ACNBC Residential Standards 1977 is referenced for recommended minimum values for thermal resistance. Other requirements in the NBC 1977 are generally the same as in NBC 1975 and the ACNBC Residential Standards 1977, but with more provisions relating to attics and roof spaces to reflect experience with roof space condensation in the 1970's. Where roof slopes are less than 2 in 12, or there is no attic, there are requirements for: vents with an area $^{1}/_{150}$ of the ceiling area uniformly distributed on all sides (this is twice the area otherwise required); cross purlins, at least 2 in x 2 in., across the top of the joists, with the insulation at least 1 in. below the top of the joists (to improve the overall effectiveness of the venting); and use of Type 1 vapour barrier over the ceiling, installed so that all joints are at framing members, with holes for electrical boxes and similar penetrations, sealed with caulking or tape. There are also general requirements for:

- weather-stripping on access hatches;
- taping of ductwork in attics;
- sealing of clearances around chimneys and gas vents (with non-combustible material) to prevent air leakage; and,
- capping or sealing of hollow masonry units at or near the ceiling to prevent moisture in the voids from entering the roof space (this was to prevent air leakage into roof spaces via fire separations between units in multiple dwellings).

The general requirement for mechanically ventilated rooms is the same as in NBC 1975 and 1970, but there is an additional clause calling for a mechanical exhaust capacity of 100 cfm (at 0.1 in. of water static pressure) in dwelling units heated with other than fuel fired equipment within the residential unit. This is a reflection of condensation problems experienced with electrically heated houses during the previous decade.

Provisions in Part 4 of the NBC 1977 are the same as in NBC 1975 except that, where materials on the cold side of the insulation have a resistance to water vapour flow equivalent to that of a vapour barrier, a ventilated air space or other means is to be provided to remove water vapour that passes through the component having the major thermal resistance (this is similar to requirements in NBC 1965). There is also a requirement, under the section on wind and rain penetration, to limit the amount of air exfiltration and infiltration at junctions of components.

NBC 1980

Requirements in Part 9 are similar to those in NBC 1977, with the following changes or additions:

- Vapour barriers need not extend across framing members of exterior walls if the interior finish consists of panel type materials attached to all framing members with a continuous bead of adhesive, in addition to nails or staples (this is implicit recognition that continuity of protection against air leakage, rather than vapour transfer, is required).

- Cross purlins on top of roof joists, where there is no attic, can be omitted where the roof slope is 1 in 6 or greater, if the joists are in the same direction as the roof slope and the minimum clearance between the insulation and roof sheathing is 75 mm. Vents in such roofs ($_{1/300}$ of the ceiling area) are to be located so that 50% of the area is near the lower end and 50% near the ridge.

- The lower portion of mansard or gambrel style roofs need not be ventilated; upper parts are to be ventilated as with other roofs, except that at least 50% of the vent area is to be located at the junction of the lower and upper roof.

NBC 1985

The NBC 1985 refers to CAN2-51.33 Vapour Barrier Sheet for Use in Building Construction, which replaced CGSB 70-GP-1(d). Holes through vapour barriers, such as those for services, are to be sealed to protect the integrity of the vapour barrier.

All joints of vapour barriers are to occur at supporting members and are to be sealed or lapped 100 mm.

Ceiling insulation is to be placed so that it does not restrict the flow of air through the vents or roof space.

NBC 1985 contains an appendix providing comments on various clauses. It notes that the prevention of the leakage of interior air into roof and wall spaces is far more critical than reduction of vapour diffusion. It also states that, while Part 9 refers only to vapour barriers, these can also act as air barriers. The need to seal openings cut in vapour barriers, and to give attention to other air leakage paths, is stressed.

NBC 1985 omits the requirement for exhaust systems in houses without fuel fired heating systems. Instead it calls for mechanical ventilation in all houses, with a capability of at least $^1/_2$ ach. The appendix refers to the tendency for greater airtightness in houses, and the need for mechanical ventilation for acceptable indoor air quality in winter. No reference is made to humidity control.

Requirements for buildings not qualifying under Part 9 are incorporated in Part 5 of the NBC 1985. There are separate sections for control of vapour diffusion and control of air leakage. The requirements for vapour barriers are the same as in NBC 1977. The section on control of air leakage calls for an effective barrier to air exfiltration and infiltration through materials, joints and junctions, at a location that will prevent condensation within a building assembly subjected to a temperature differential, a differential in water vapour pressure, and a differential in air pressure due to stack effect, mechanical systems, or wind. It is noteworthy that the air barrier is not required to be located on the high vapour pressure side of the major thermal resistance, as required in all previous editions beginning in 1965.

NBC 1990

In Part 9 of the NBC 1990, there are separate clauses dealing with air barriers and vapour barriers. Polyethylene sheet used for either is required to conform with a new standard, CAN/CGSB-51.34M. Thermally insulated wall, ceiling and floor assemblies are to be constructed so as to provide a continuous barrier to leakage of air from the building interior into envelope spaces. Air barrier protection is to possess the characteristics necessary to provide an effective barrier to air exfiltration under differential pressures due to stack effect, mechanical systems or wind.

Where the air barrier protection consists of an air impermeable panel type material, all joints are to be sealed to prevent air leakage. Where it is formed of flexible sheet material, all joints are to be sealed, or lapped at least 100 mm and clamped, as between framing and rigid panels.

Where the air barrier protection consists of a material with water vapour permeance less than that permitted for Type 2 vapour barriers, it is to be installed at a location where the temperature will not be below that of the dewpoint temperature of the interior air when the outdoor temperature is 10°C above the 2.5% January design temperature (no reference indoor dewpoint temperature is given).

There are requirements for maintaining the continuity of the air barrier at intersections of interior walls with exterior walls, ceilings and floors, and at penetrations created by doors and windows, access hatches, services, chimneys and vents (this is similar to requirements for vapour barriers in NBC 1985). Requirements for sealing of joints in ductwork through unheated spaces, and hollow masonry units, where they penetrate roof spaces, are retained. Other requirements for the installation of vapour barriers are similar to NBC 1985, except that no additional vapour barrier protection is required for insulation which, when installed, has a permeance less than that required for vapour barriers; also, the exemption from venting roof spaces of 1-storey buildings, contained in NBC 1985 and earlier editions, is withdrawn. The Appendix includes more information on air leakage protection than in NBC 1985.

Requirements for mechanical ventilation are similar to NBC 1985, except that the minimum capability is 0.3 ach, including the basement volume.

The NBC 1990 incorporates a number of new provisions for dampproofing of concrete slabs-on-ground in enclosed portions of buildings, and controlling the entry of soil gas. All such slabs are to be placed on at least 100 mm of granular fill. Dampproofing below the slab is to consist of not less than 0.15 mm (6 mil) polyethylene, with joints lapped at least 300 mm (not 100 mm). Roll roofing is not identified as acceptable. The slab is to be sealed, around the perimeter, to the inner surfaces of the adjacent walls with flexible sealant. All penetrations of the slab are to be sealed against water vapour and soil gas leakage. Some permanent means of sealing floor drains, to prevent the upward flow of water vapour and soil gas, is required (this can be the standard water trap if there is provision to maintain water in the trap). The Appendix contains further advice on controlling the infiltration of soil gas.

Masonry walls that require dampproofing, and which are to be dampproofed on the exterior surface, are to have a course of masonry units without voids, or are to be sealed with flashing, at or below the level of the adjoining floor slab. Where mineral fibre, or crushed rock back-fill, is used against the exterior surface of the foundation wall, it is to extend to the footing level to facilitate drainage of ground water to the drainage system.

The general requirement for providing sufficient insulation to prevent moisture condensation on interior surfaces of the envelope, and to ensure comfortable conditions for the occupants, has been extended to include assemblies separating interior space from the exterior soil. There are no specific requirements for the extent of thermal insulation to be provided.

Requirements in Part 5 for the control of vapour diffusion and air leakage are the same as in the NBC 1985.

APPENDIX H

LIST OF PERSONS INTERVIEWED

List of Persons Interviewed

Alan Bowles	EMR (formerly HEP)
Richard Desserud	NRC-NBC (formerly CMHC)
Oliver Drerup	Drerup Construction Limited
Tom Hamlin	CMHC (Research Division)
John Haysom	NRC-NBC (formerly Scanada Consultants Limited)
A.J. Houston	CMHC (Research Division)
Tom Kerwin	CMHC (PID)
Ken Latta	NRC (retired)
John Lovatt	Morrison Hershfield Limited (formerly EMR-BETT)
Gint Mitalas	NRC (retired)
Ross Monsour	CHBA
John H. McKenzie	Consultant, formerly with Masonite Canada
Don Onysko	Forintek Canada Corporation
R.E. Platts	Scanada Consultants Limited
Rick Quirouette	Morrison Hershfield Limited (formerly NRC)
Mark Riley	EMR Canada (R-2000)
Ken Rauch	CMHC (Professional Standards Division)
Jacques Rousseau	CMHC (PID)
Dave Scott	Morrison Hershfield Limited (formerly NRC)
Frank Szadkowski	EMR (formerly HEP)
John Timusk	Centre for Building Science, University of Toronto
Jim H. White	CMHC (Research Division)

APPENDIX I

Forum on Canadian Moisture Research

FORUM ON CANADIAN MOISTURE RESEARCH

MAY 19, 1992

QUEEN ELIZABETH HOTEL, MONTREAL

Participants:

Tom Kerwin, CMHC (Chair)
Alvin J. Houston, CMHC
Tom Hamlin, CMHC
Dr. Mark Bomberg, NRC
William Brown, NRC
Dr. Anton TenWolde, U.S. Forest Products Laboratory
Dr. Arne Elmroth, University of Lund
Robert Platts, Scanada Consultants Ltd.
Dr. Robert Booth, Hansed Booth
John Vandeklaf, Buchan, Lawton, Parent Ltd.
Dave Scott, Morrison Hershfield Limited
Grant Wilson, Morrison Hershfield Limited
Bob Sloat, Canadian Home Builders Association
André Gagné, APCHQ
Gary Reardon, Reardon Construction and Development Ltd.
Lewis Nakatsui, Lincolnberg Homes
Dr. John Timusk, University of Toronto
Dr. Eric Burnett, University of Waterloo
Dr. Don Onysko, Forintek Canada Corporation
Al McKinley, Canadian Automated Building Association
Eric Jones, Canadian Wood Council (observer)

INTRODUCTION:

This forum on Canadian Moisture Research was convened by Canada Mortgage and Housing (CMHC) to provide advice to CMHC on the following issues:

1. To provide comments on the draft document "Moisture in Canadian Wood Frame Construction: Problems, Research and Practice from 1975 to 1991", prepared under contract to Morrison Hershfield Limited and authored by Grant Wilson.
2. To provide opinions on the areas of moisture research that have now been concluded, and to generate suggestions on future moisture research that should be undertaken.

The following additions to the Moisture Summary Document were made by the meeting participants:

- findings, if any, from the HUDAC MARK III and IV projects with respect to the influence of back painting of wood based siding;
- findings of the BETT program with respect to moisture problems;
- discussion of moisture problems in CMHC's report to EMR on the CHIP program;
- discussion of Saskatchewan Research Council's work on sagging of gypsum board ceilings;
- impact of CHBA (HUDAC) planning of moisture related work;
- possible variation in importance of adfreezing as a deterioration mechanism established by the Ontario New Home Warranty Program;
- the role of various post secondary educational institutions in transferring moisture related technology into codes, standards and associated documents;
- moisture related studies on early stressed skin panels and later developments of wall systems based on solid polystyrene insulation;
- research work regarding the contribution of passive vent stacks to humidity reduction in east coast housing;
- the history of asphalt composition sidings in Atlantic Canada and resulting rotting of sheathings; and

- the history of investigation of deterioration behind wood based sidings and subsequent discovery of deteriorated sheathings behind vinyl and aluminum siding (wood or wood based sidings as tell-tales).

Key remaining areas that require a co-operative research effort by government, industry, academic and consultant communities include the following:

- increased understanding of the basic properties of construction materials including moisture storage, coefficients of moisture and thermal expansion to allow comparison of materials on a multi-faceted basis;
- further integration of current knowledge on the influence of moisture on materials into a manageable systems context;
- "risk analysis" leading to a ranking of the relative safety or level of forgiveness in systems with respect to long term durability;
- definition of air and vapour barrier performance characteristics to include the impact of liquid water on external air barriers and a more rational basis for the permeability of vapour barriers;
- better understanding of insulated sheathing, its "R" value, water vapour transmission and moisture balance with the remainder of the wall;
- for spaces below grade, determining the role/effectiveness of dampproofing, air and vapour barriers, the use of concrete as a moisture source/sink and the control of ground water;
- the review/development of construction practices to decrease the moisture load in houses at occupancy (e.g. implications of alternate framing systems that employ composite materials, material selection or trade sequencing);
- in well ventilated houses, how can humidity safely be added;
- design for moisture control requires improved modelling tools capable of being used by builders/designers for a range of climatic conditions and material or systems selected;
- the moisture balance of retrofitted houses is a major concern due to the variety of materials, systems, original and retrofit construction practice and building operation;
- moisture problems in existing multi-unit residential buildings will require much larger support for research that is currently provided for single family dwellings.

A round table discussion ensued around each of the following topics that are in large part drawn from the conclusions in the moisture summary report.

Key Science Issues

Is More Work Required for Moisture Sensitive Sidings in Atlantic Canada?

- The majority of current residential construction in Atlantic Canada employs vinyl siding in place of wood or wood based alternatives, thus builders have in large part eliminated the problem of deteriorated siding by changing materials.
- The moisture performance of the back-up walls clad with vinyl is not well known.
- In Newfoundland, rough sawn clapboard, back primed and stained on the exterior applied over a weather barrier without strapping appears to be performing well. Recoating time is approximately 5 years.

Have Wet Sheathing/Framing Problems Been Resolved?

- In many cases builders have reverted to board sheathing and no longer report problems.
- Problems continue to result from the use of wet framing lumber, a condition driven by the cost of kiln-dried lumber.

What Additional Practices are Recommended Over Current Construction in Atlantic Canada?

- use of lumber with a moisture content below 20%;
- wider application of code requirements for ventilation of units, especially in areas where wood heat predominates; and,
- use of strapping under siding to promote drying of the siding and outer wall system. (Building practice in Japan and Sweden, areas of similar climate, is changing to, or has long been using this practice).

Can Science Offer Practical Solutions to Reduce Paint Failure in Atlantic Canada?

- The Swedish system of coating works well. It includes a solvent based oil penetrating primer followed by a pigmented (UV protected) over coating followed by oil or latex top coats. This system does not back prime the siding in most cases.

What Practices are Recommended for Painted Siding?

- This issue was thought to be too complicated to consider as one concern.
- Retrofit systems must take account of the operation of the current wall system, which implies an analysis of building operation and a condition report before recommending a retrofit approach on a specific building?

Are Sheathing Systems Adequate for Controlling Wind Action on Insulation?

- Studies have confirmed that local cooling does result from wind action confirming the need for a weather barrier.

Do Moisture Problems Result from the Use of Low Permeance Sheathings?

- Drying in systems that employ low permeance sheathings is mainly a function of the joint design.
- If the joints are not sealed, the wall can dry to the inside or out during the drying season.
- Quebec is not using waferboard or low permeability sheathings but "natural" materials.

What Δ P (wind, stack or mechanical) is a Wall or Ceiling Subjected to by Region?

- No comments were made with respect to the above, or to changes in humidity or airtightness requirements by region.

Is Current Allowable Pressurization (F326) Reasonable in Current or R2000 Construction?

- No comments were made.

What Additional Work is Required on Dynamic Walls?

- The potential energy savings for these systems must be quantified.
- Homeowners will tend to maintain a dynamic wall if the heat is used to heat domestic hot water.

Is the Current Vented Roof Construction Adequate or Logical in all Regions?

- The overall science of moisture balance in roof spaces has never been established.
- Further analysis would be useful in qualifying current prescriptive requirements.

Will Current NBC Requirements for Basement Construction Eliminate Moisture Problems?

- There continues to be problems with basement construction practice across Canada; practice that does not necessarily conform to the NBC.
- With current trends towards using the basement as habitable space, there is increased need to understand and control moisture flows between the habitable space and adjacent concrete foundation.

What Moisture Problems or Envelope Design Issues Require Improved Performance Predictions Through Modelling?

- Modelling tools must eventually be used to support prescriptive requirements in Part 9 of the NBC.
- Models must consider how they will be used and provide an interface suitable for the person expected to use them.
- Models must be able to predict the cumulative effect of moisture in spaces or systems, within established time frames, to allow the user to compare predicted vs acceptable.
- Models should assist the user in establishing what is important in a particular systems context (for example could a vapour barrier be eliminated from a particular system within a geographic region).
- Additional work is required to compare models to systems that do or do not work, leading to a knowledge based expert system to solve moisture problems and guide new design.

Construction Practice Issues

Increases in Energy Efficiency

- On new construction which is better insulated, sealed and ventilated, we need to understand better the effects of thermal bridges and their impact on surface temperatures, and the overall impact on human comfort.
- Attics with large amounts of insulation leave the roof space very close to exterior temperature, which in turn makes condensation very possible if air leakage is not carefully controlled.
- As insulation levels rise, brick veneer is placed in a more severe climate and wall systems in general have more difficulty drying.

Framing Practices

- The outward bowing of 2 x 6 studs presents a problem with keeping walls straight.
- New systems are currently being marketed that eliminate many of the standard thermal breaks at studs and plates, thus avoiding mould, mildew and dust staining.
- Research should look to the R2000 analysis to establish why these systems work.
- With a trend to industrialization, which controls the construction process within a factory, can the moisture tolerances of these enclosures be reduced?
- Shorter construction cycles allow reduced time for drying.
- The most severe exposure for wood frame construction is in the first few weeks of construction, before closing.

Codes and Standards

- Current codes respond to the worst case scenario - can regional differences be accommodated to reduce requirements (e.g. vapour barrier requirements)? If we move off current requirements, we must be able to define regional reductions.
- Are current requirements for venting of cathedral ceilings appropriate?
- Changing to a performance approach to moisture requirements must deal with systems performance.
- Test procedures are required to establish the airtightness of junctions, joints or connections between materials.

Design Process

- Encouragement is needed to create forgiving systems, based on building science, that bypass problems.
- Solutions need implementation and demonstration.

Environmental Issues

- Improvements in data on material emissions or process emissions (CFC's) would assist builders in selecting materials.
- Additional data on embodied energy for materials would also assist with material selection, but it is difficult to predict the direction of this field.
- Effective, reliable ventilation systems require development to provide air distribution to all spaces, with control based on a demand system.
- The Canadian Automated Building Association will consider control systems necessary to overcome regional climate difference and variations in airtightness.
- There continues to be a concern for hypersensitive occupants.

Technology Transfer

Forum participants briefly reviewed the current technology transfer vehicles, including scientific/technical papers, client reports, advisory documents, codes and standards, seminars, workshops, training courses, demonstrations, videos, TV programs, and the popular press. The audience was recognized as builders, sub-trades, manufacturers, suppliers, architects, engineers, students, researchers, regulators, warranty programs, and consumers.

- Many of the process links are now in place to bring research, design and development information to the builders and consumers. Training programs can be delivered through the provincial warranty offices with direction from the National Education and Training Advisory Committee of the Canadian Home Builders Association (CHBA) and the Publications Subcommittee of CHBA's Technical Research Committee.
- Strategies should work toward consumer pull vs pushing technology at the builders.
- Technology transfer through codes and standards is most powerful.

- Convincing a select number of the "better" builders of the advantages of new technology will change the inertia in the industry.
- TV/video media should be employed more often.

Forum Wrap Up

There was a general consensus that the issues raised during the day's discussion should be refocused in a number of additional meetings, to assist in shaping a rational on-going research planning policy. In doing so, Canadian researchers and builders should continue to maintain their contacts with Nordic and American researchers to ensure that research dollars are applied in the most useful direction.

APPENDIX J
BIBLIOGRAPHY

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BIBLIOGRAPHY

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APPENDIX K
GLOSSARY OF ACRONYMS

Appendix K

Glossary of Acronyms

(1)	ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineering.
(2)	ASTM	American Society for Testing and Materials.
(3)	BETT	Building Energy Technology Transfer Program.
(4)	CBD	Canadian Building Digest.
(5)	CCA	Department of Consumer and Corporate Affairs.
(6)	CGSB	Canadian General Standards Board.
(7)	CHBA	Canadian Home Builders Association (was HUDAC).
(8)	CHIP	Canadian Home Insulation Program.
(9)	CMHC	Canada Mortgage and Housing Corporation.
(10)	COSP	Canadian Oil Substitution Program.
(11)	CSA	Canadian Standards Association.
(12)	CSCE	Canadian Society of Civil Engineers.
(13)	CSSRMA	Canadian Siding, Soffit and Rain-Goods Manufacturers Association.
(14)	DBR	Division of Building Research (became IRC) of the NRC.
(15)	ELA	Equivalent Leakage Area.
(16)	EMR	Energy, Mines and Resources Canada.
(17)	ERDA	Energy Research and Development Agreement.
(18)	FTA	Free Trade Agreement.
(19)	GATT	General Agreement on Tariffs and Trade.

(20)	HEP	Home Energy Program.
(21)	HRAI	Heating, Refrigerating and Air Conditioning Institute.
(22)	HUDAC	Housing and Urban Development Association of Canada (became CHBA).
(23)	IRC	Institute for Research in Construction of the NRC (was DBR).
(24)	MAPP	Moisture Assessment Prescriptive Procedure.
(25)	NAFTA	North American Free Trade Agreement.
(26)	NBCC	National Building Code of Canada.
(27)	NECA	National Energy Contractors Association.
(28)	NHA	National Housing Act.
(29)	NIST	U.S. National Institute of Standards and Technology (formerly NBS).
(30)	NRC	National Research Council of Canada.
(31)	OHBA	Ontario Home Builders Association.
(32)	ORTECH	Ontario Research and Technology International.
(33)	PERD	Interdepartmental Panel on Energy Research and Development.
(34)	SBPO	Spun-Bonded Polyolefin.
(35)	SRC	Saskatchewan Research Council.
(36)	UFFI	Urea Formaldehyde Foam Insulation.
(37)	VAPP	Ventilation Assessment Prescriptive Procedure.