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DIVISION OF BUILDING RESEARCH

HUMIDITY, CONDENSATION AND VENTILATION IN HOUSES

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October, November and December 1983

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C.B. Crawford
Director
DBR/NRC

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INTRODUCTION

The Building Science Insight '83 program is the 23rd presentation of the successful seminar/workshop series which the Division of Building Research initiated in 1964; (name change was designed to draw attention to the science reporting intent of these sessions). The Insight program aims to provide the building science explanations for building performance problems in general and the problems of high humidity and surface and concealed condensation in houses in particular, for this year's program. It does not condemn any material or product nor does it recommend any in particular. We have endeavoured to communicate an understanding of the physical performance of the building envelope.

The Insight program is intended for an audience which includes architects, engineers, educators, builders, suppliers and building officials, as well as others involved in the building design and construction process.

SUBJECT CONTENT

The Division of Building Research and Canada Mortgage and Housing Corporation have been increasingly preoccupied with inquiries and complaints of moisture damage in housing. The problems are varied and range from continuous window condensation, to exterior wall siding and masonry damage, to fungus attack on interior surfaces, exterior sheathings and trusses in attics. There are condensation problems in every part of Canada and they vary in type and severity. However, they are all related to an uncontrolled migration of moisture on and in the building envelope and the changing patterns of natural as well as mechanical ventilation in houses.

Since 1973, there has been a significant change in construction practices and particularly in relation to insulation levels and airtightness of the building envelope. While thermal upgrading of the building envelope is undeniably the correct route, it is also linked to the moisture control performance of any wall or roof system. Increased airtightness also has several important implications. Notwithstanding the quality of the indoor air, there will be a natural tendency for almost all new and retrofitted houses to operate at a higher indoor humidity level than the normal.

With this in mind we have developed a program to illustrate the varied types of condensation problems that may occur, explain the active processes involved in some of these problems and discuss in detail the principal factors surrounding these phenomena, i.e. sources of moisture, choices of construction detailing, and current ventilation practices.

Two general discussion periods were held during each afternoon session to develop further the material presented in the morning. Some of the most frequently asked questions were chosen from these discussions, answered by the authors and included as a supplementary part of these proceedings.

Itinerary and Logistics

The Building Science Insight '83 program was held in thirteen major centres of Canada: St. John's, Halifax, Moncton, Rimouski, Québec City, Montreal, Ottawa, Toronto, Winnipeg, Saskatoon, Edmonton, Yellowknife and Vancouver. In some centres, the Insight program was presented several times: three times in Toronto, twice in Ottawa, twice in Edmonton and twice in Montreal. A third unscheduled session was also presented in Montreal on December 8, because of a significantly larger preregistration than anticipated.

A total of 1455 persons (1392 paid) attended the nineteen sessions held across Canada; of this total, approximately 16% were architects, 7% were consulting engineers, 5% were technicians and technologists, 15% were construction and project managers, 3% were associated with material manufacturing, 4% from the teaching community, 8% with municipal inspection services and the remainder, 42%, included those not identified by profession as well as those associated with a variety of other interests, trades or professions.

A Note about the Authors

The Building Science Insight program was presented in both official languages: English and French. To do so, many authors were asked to participate in the program. Most authors presented their talks in both English and French, with one exception; the talk on "Ventilation of Houses" was presented by different authors in different cities.

The principal authors of the written papers that follow, are Jacques Rousseau of Canada Mortgage and Housing Corporation, and R.L. Quirouette, Madeleine Z. Rousseau and G.O. Handegord, all members of the Division of Building Research of the National Research Council of Canada.

Special Assistance

During our cross-Canada tour, we were pleased to have with us Mr. Jim White, a Senior Research Officer of the Canada Mortgage and Housing Corporation, to participate as one of the panelists during the afternoon discussion period. While participating in the discussions, Jim has compiled, grouped and classified a comprehensive list of most of the questions that were asked during these discussion periods, so that members of the research community may get a better idea of the queries and concerns of practicing members of industry.

Acknowledgements

The Building Science Insight '83 program has involved numerous people in the development and preparation of the technical material. Many critics have participated, but in particular the assistance of Mr. Gordon Plewes and Mr. Jim White is gratefully acknowledged, as many of their suggestions about technical content were integrated and used in the program.

Special thanks are extended to Mr. Ron Biggs for taking time from a very busy schedule to assimilate and present Mr. Gus O. Handegord's talk on "Ventilation of Houses" in Yellowknife, Vancouver, Saskatoon and Winnipeg. Special thanks are also extended to Gilles Poirier for the doubly difficult task of assimilating and preparing the French equivalent presentation of Mr. Handegord's talk.

The Building Science Insight program depends a great deal on graphic material to communicate the subject content; thanks are extended to Mr. Don Hobbs of the Graphics Section of DBR for days and weeks devoted to the preparation of drawings and photographs used in this program. We also thank Mr. Gerry Makahon for his assistance during the western part of our tour.

Very special thanks are extended to Gail LeBlanc and Jeanne Chagnon for their untiring and diligent assistance in typing draft after draft of the manuscripts, for the preparation of the pre-registration material and the information service they provided during the promotional and delivery period of the Insight '83 program.

Finally, and most important thanks are extended to you, the participants, for your interest and active participation.

B.F. Stafford, Promotion and Travel Manager
R.L. Quirouette, Programme Co-ordinator.

RAIN PENETRATION AND MOISTURE DAMAGE IN RESIDENTIAL CONSTRUCTION

by

Jacques Rousseau

INTRODUCTION

The Canada Mortgage and Housing Corporation (CMHC) is interested in rain penetration and moisture damage because CMHC is involved in much of the housing built across Canada. We own houses, have insured their mortgages and have participated in cost sharing programs with the provinces, to build social housing projects. In the early 1980's, we received indications of moisture-induced problems. In 1982, the corporation engaged a firm of consulting engineers to determine the types of problems encountered in different parts of Canada, the factors surrounding these problems and their probable causes. The purpose of this paper is to share the findings of this research.[1]

PROBLEM DEFINITIONS

The types of moisture-induced problems found were grouped and classified by the consultants into five types: mould and mildew, window condensation, attic condensation, condensation in wall cavities, and exterior siding damage.

Mould and mildew growth was considered to be serious where growth or staining was observed in large patches on the walls or ceilings, as well as in corners.

Window frame mould, rot, or other localized water damage in the general area of the window were considered to be a recordable problem of window condensation.

Condensation in the attic was considered serious in two cases: the first is when excessive moisture has been absorbed by the framing members and the sheathing, causing the moisture content in the wood to exceed 22%. When the moisture content of the wood sheathing and structural members exceeds 22% of the weight of dry lumber for an extended period of time it can result in rot. The second case is when mould and mildew growth covers more than 50% of the attic sheathing and roof joists.

Moisture problems in wall cavities were considered major when the moisture content of the wood studs and sheathing exceeded 22%.

Two types of exterior wall siding problems were considered significant; buckling or warping of more than 50% of a wall area was considered to be a major problem. Paint damage was considered a major problem when the total affected area was greater than 0.3 square metres.

In general, no area in Canada is without some type of serious moisture-induced problem. The type and extent of the problem varies across the country. Between 1973 and 1981, CMHC was involved in building 689 000 housing units. This represents approximately 35% of the units built in Canada during that period. The proportion of problems reported in this study may or may not be representative of the remainder of the national housing stock.

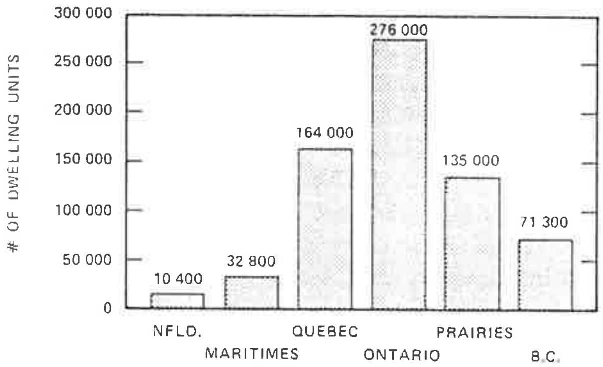
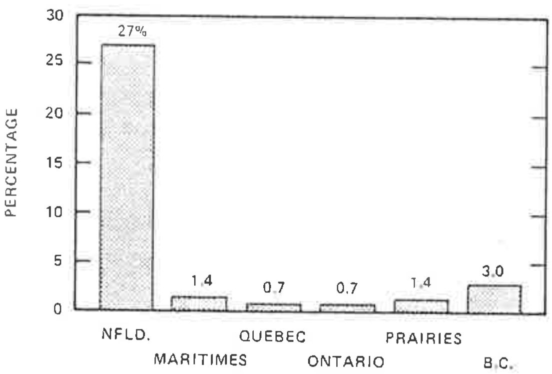


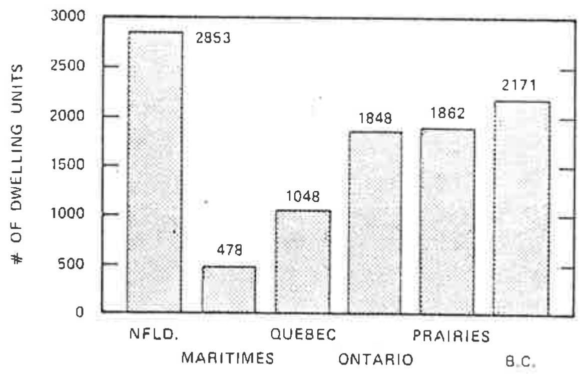
Figure 1

CMHC (NHA) housing stock, between those years, was distributed throughout Canada as shown in Figure 1. Of the total number of units built in Newfoundland between those years, 27% were found to have serious moisture-related problems (Figure 2). In other provinces the percentage of problems is much lower; however, if we examine the actual number of units with serious rain and moisture problems, there is still cause for concern (Figure 3). British Columbia housing exhibited serious moisture problems in over 2000 units. Ontario and the Prairie provinces follow closely behind and the Maritimes have the least.



% OF NHA HOUSES WITH PROBLEMS, BY REGION

Figure 2



MOISTURE PROBLEM HOUSES BY REGION

Figure 3

It is important to note that these numbers represent only the problems reported by our inspectors, municipal inspectors and local housing agencies. Some problem houses had already been repaired at the time of the study, and were not counted in this survey. The actual number of problem houses was therefore somewhat higher than indicated. In any case, there are at least 10 000 housing units in Canada which have problems serious enough to cause a financial loss.

MOULD AND MILDEW FORMATION

Mould and mildew formation (Figure 4) is to most of us an aesthetic problem. However, it may also be a concern from a psychological point of view and there is probably an air quality, and thus a health-related, aspect to consider as well.

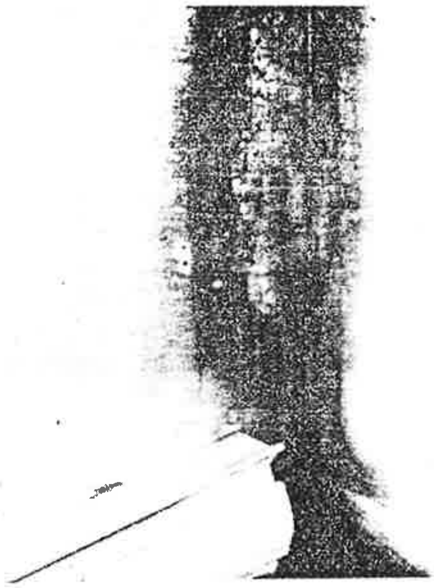


Figure 4

Mould and mildew formation on walls is caused by creation of an environment favourable for its growth. Houses with this type of problem had, in general, two things in common: high room side relative humidity levels (over 50%) and cold wall surfaces. The houses were also located in climate zones having particular, but different, sets of conditions.

The room side relative humidity depends on the occupant's lifestyle, the number of air changes per hour and, to an unknown degree, the moisture released by the building itself.

Cold inside wall surfaces tended to promote surface condensation and thus a favourable environment for the growth of fungus; this was probably the result of cold air infiltrating through the exterior wall envelope, air circulation within the wall cavity, or thermal bridging. The low thermal resistance value of a wall may result from inadequate insulation or from inadequate construction detailing and poor workmanship.

The two climate conditions referred to are defined as either a sustained low outdoor temperature, such as in northern areas; or as moderate seasonal temperatures, with high incidence of rain, and little sunshine. These latter conditions will be found in British Columbia. Mould and mildew were found in all geographical areas with climate conditions as defined above.

The most serious occurrence of reported mould and mildew problems was in Ontario, with 1072 units, most of which were in Northern Ontario, followed by British Columbia with 912 units. There were few problems of this type in the Maritimes (Figure 5).

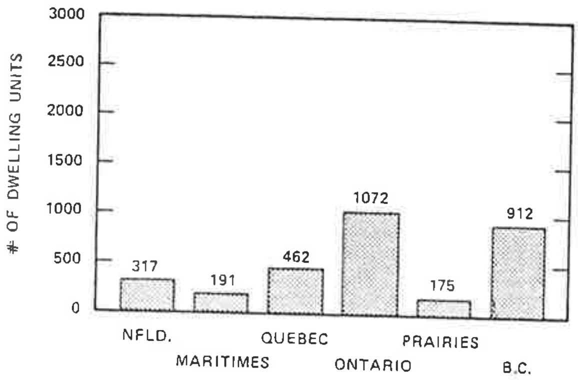


Figure 5

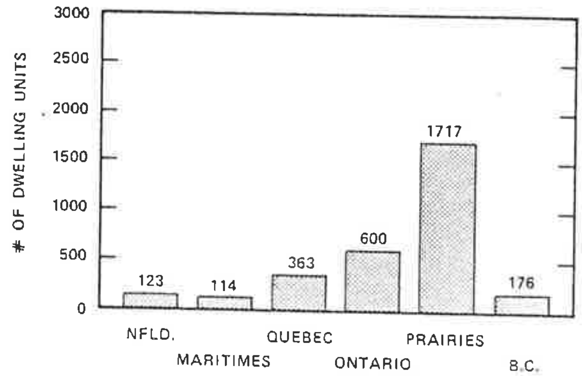


Figure 6

WINDOW CONDENSATION

The types of damage associated with window condensation are as follows: condensation runoff that has caused damage to the window frames; soaked and stained plasterboard edge below the window sills; rotted or mouldy floor coverings below the window; corrosion of wall connections for baseboard heaters; condensate running into walls and rotting the frame members, and in some cases leading to freeze-thaw damage of masonry materials.

Under extreme weather conditions, minor condensation occurs on all windows. Figure 6 shows the distribution of serious window condensation problems by region or provinces in Canada. In very cold areas, such as the Prairies, which also have many hours of bright sunshine, there is a significant swing in glass surface temperature from day to night and vice versa. Problems were caused by melting of window frost, when the sun warms up the glass during the day.

Some problems were reported on the West Coast, especially in the Vancouver/Victoria area, although this region is not affected by very cold weather. The inside surface temperature of single glazing may well be below the condensation temperature of the inside air and thus contribute significantly to the problem of window condensation.

CONDENSATION IN ATTICS

Attic condensation (Figure 7) may not be a problem if it can dry out. However, if it manifests itself by water leakage through the ceiling, the problem is serious. Attic condensation has been found to be the cause of deterioration of interior room finishes, due to melting and gravity flow of attic water. It has also been the cause of rot of roof truss members or sheathing, to a point where structural collapse is possible. Corrosion of truss plates, deterioration of insulation and framing members around electrical fittings, decrease of thermal resistance of insulation, due to

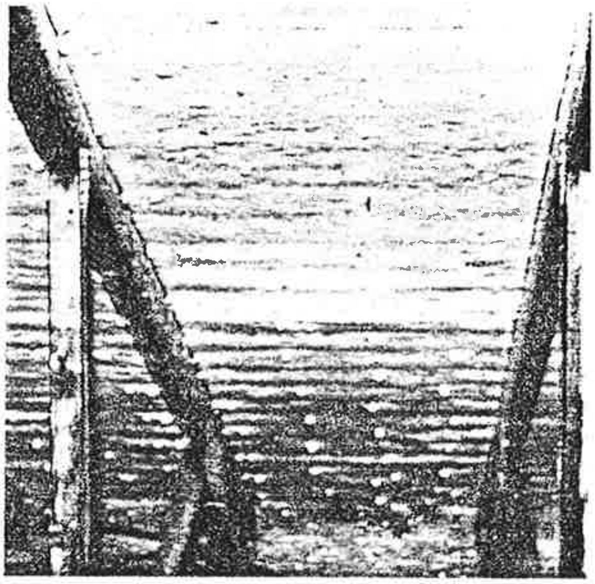


Figure 7

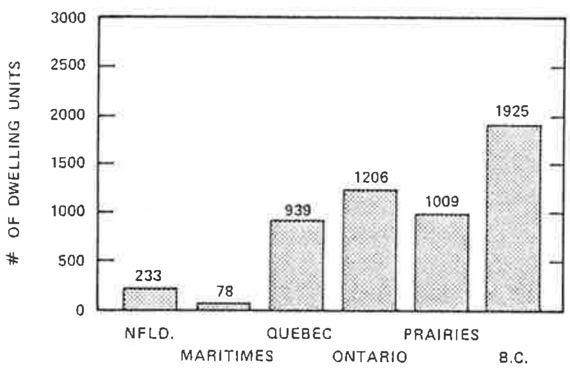


Figure 8

excessive moisture dripping from condensate accumulated on roof sheathings, are often related to attic condensation.

The frequency of condensation problems was high for two types of climatic region (Figure 8). In northern areas and in coastal regions the climate affects attic condensation in completely different ways. Of the two, the more severe cases were found in areas having a relatively mild but prolonged heating season, coupled with high outside relative humidity and a minimum of sunshine, such as would be found in British Columbia.

In this type of weather regime, the combination of high moisture content in wood and above freezing temperatures provides an excellent environment for the growth of mould and mildew and for the promotion of rotting.

The other type of climate condition associated with attic condensation combines a prolonged and very cold winter, lots of sunshine throughout the year and a strong drying potential in the spring. These climate conditions are usually found in northern areas such as Northern Ontario and the Northwest Territories. When houses in these regions have moisture-related problems in the attic, it is usually the result of moisture escaping into attic spaces; this moisture subsequently freezes on sheathing and truss members and thaws out rapidly during the spring. This can lead to melt water running into the walls or the living spaces below, if thawing takes place so rapidly that water can't evaporate.

Notwithstanding the climate characteristics of a region, the following indoor conditions were also noted: although there was no significant difference found in the generation of moisture between families living in a problem house and families in a house with no problems, higher indoor relative humidity levels existed in problem houses, and houses where major attic damage occurred had poor ventilation. The soffit vents were either covered or non-existent. Where rotting had occurred, the following contributing factors were found: condensation on the ceiling, high RH levels in the attic space, wet spots in the attic insulation, poor attic ventilation, and houses which were not airtight.

WALL CAVITY PROBLEMS

Moisture problems in wall cavities (Figure 9) occurred between the exterior siding and the inside vapour barrier. The elements that can be affected are the wood studs and wall plates, the sheathing and the insulation.

The wall damage observed by our inspectors was mostly localized: that is, there was rotting of the elements near an electrical outlet, often combined with moisture saturation of the sole plate and the wall sheathing.

Figure 9

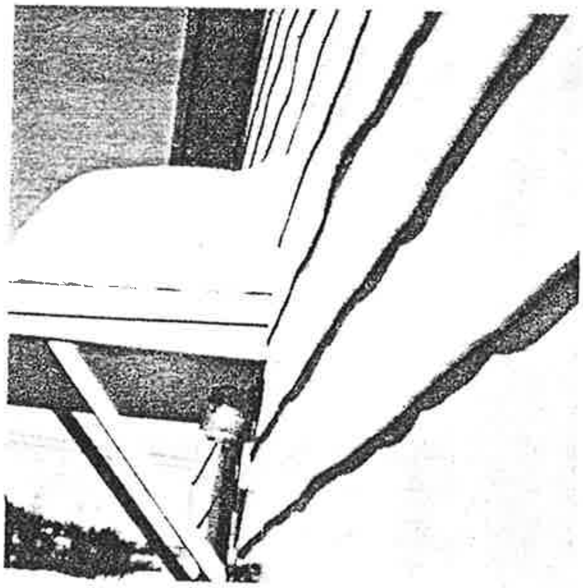


Figure 10

Moisture problems in wall cavities were found in regions where the following weather conditions prevailed: cold temperatures, especially during April and May, a high incidence of driving rain during the winter and spring, little sunshine, particularly during the spring, and high wind conditions with the housing unit exposed.

There is a higher incidence of this problem in the walls of the second floor. This would seem to indicate a stack effect; i.e. moist air rising through the unit is going out through the exterior walls of the upper level.

SIDING DAMAGE

Major types of siding damage encountered were the following: buckled siding (Figure 10), rotted siding, paint damage, and spalling brick.

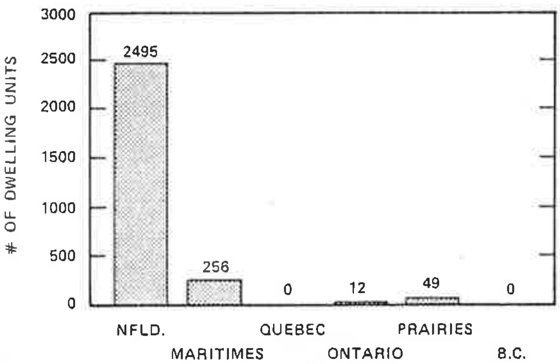


Figure 11

Figure 11 shows that siding problems are very serious in Newfoundland. It is felt that the climatic conditions of Newfoundland play an important role in the cause and frequency of this type of problem. The weather regime is as follows: low temperatures and windy conditions during spring, a high incidence of driving rain during the winter and spring, and very little sunshine, especially during the spring.

The following conditions inside the houses were revealed by the study; family lifestyles did not correlate well with the problem, but high RH levels were found in all problem houses. Paint damage was found mostly in older units, indicating that the problem had existed for some time, but was not severe enough to show up right away. It was not always possible to determine whether the condensation was due to the leakage of warm, moist air or if wind-driven rain was the source of the moisture accumulation in wall cavities.

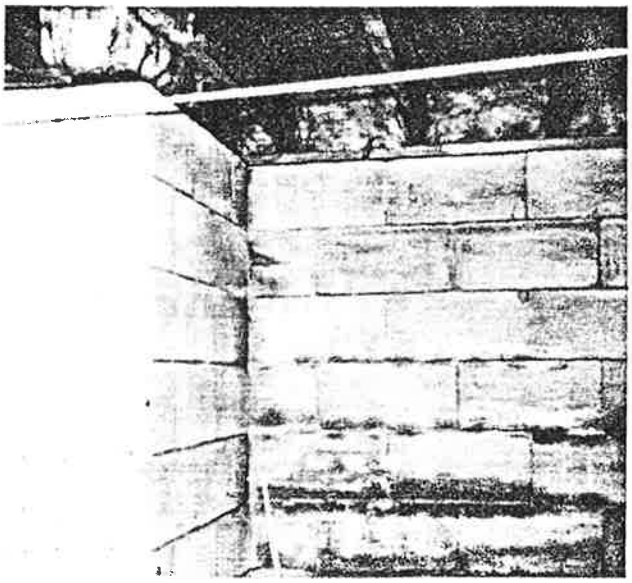


Figure 12

BASEMENT MOISTURE PROBLEMS

Basement moisture problems (Figure 12) are mainly due to water leakage and dampness resulting from rain and melting snow. Those problems reported by our inspectors are mostly due to leaky foundation walls, poor flashing details at wall junction, and inadequate foundation drainage, which often leads to flooding of the basement.

Many of the inspectors that examined the problems with insulated basement walls have concluded that poor airtightness around the insulation has allowed convection air currents to condense moisture on the cold basement wall surface behind the insulation. This resulted in water appearing from behind the insulation and thus it appeared to be a leak from the foundation wall.

SUMMARY

All of these problems are related to three conditions; 1) the indoor temperature and humidity, 2) the climate, and 3) the type of construction details used in assembly of the building envelope. Table 1 correlates the type of problem with the main cause identified. For example, mould and mildew on inside surfaces occur where high relative humidity levels are found indoors, and the prevailing climate includes cold weather or driving rain coupled with little sunshine. The cause may also have been the construction details used; that is, there may have been a thermal short-circuit or a thermal bridge or insufficient insulation in the region of the mould and mildew problem.

Considering the indoor conditions associated with all of these different problems, high indoor relative humidity is present in all cases and the interior air pressure of the house at the ceiling level was often higher than the outside (80% of the houses that reported problems were electrically heated and did not have active flues). Poor airtightness can also be associated with most of the problems reported.

The indoor conditions and the climate continually stress the house envelope. This stress is aggravated further if the region lacks a good drying season. Keeping this in mind, we can improve the performance of houses, with regards to moisture damage, by controlling some of the moisture sources, ventilating, and improving the design and construction of the building envelope.

Reduction of the amount of moisture generated will lower the level of humidity within the unit. The less moisture generated, the less there is to condense or to migrate into cavities. This is discussed in more detail in the paper that follows, titled "Moisture Sources in Houses".

Ventilation can remove the moisture that has been generated and create a favourable (negative) pressure difference across the outside walls and ceiling. This point is further discussed in the paper on "Ventilation of Houses".

With improvements to the design and construction of the building envelope, there may be a marked reduction in the passage of rain into the wall cavities, the passage of moist air into the wall and roof, and the entry of cold exterior air into wall cavities. Ventilation is used to reduce relative humidity levels within the house, which in turn helps control surface condensation on wall surfaces and on windows. However surface condensation may also be controlled with additional insulation in wall cavities and with double or triple glazing. These points are discussed further in the paper on "Control of Surface and Concealed Condensation" by Madeleine Rousseau.

However not all moisture sources can be eliminated; ventilation must be controlled, otherwise we would defeat the purpose of insulating houses; and it may not be possible to build the perfect house. There will always be a crack somewhere. A balance must be struck in our attempts at improving all three approaches, and at the same time give consideration to the homeowner's lifestyle.

CONCLUSION

The number of houses now subject to moisture damage represents slightly more than 1% of NHA housing stock. In addition, the problems are mostly aesthetic in nature and not structural at this time. However, if no action is taken to prevent the occurrence of moisture damage, the problems will continue to grow. We know that changes must be made to Canadian houses. We have initiated some changes already and more can be expected in the future. We are cooperating with the house building industry and experts in the building science field to find additional cost-effective solutions.

REFERENCES

1. Moisture Induced Problems in NHA Housing, 3 Parts, Canada Mortgage and Housing Corporation. Report prepared by Marshall Macklin Monaghan Limited, Cat. No. NH20-1/2-1983-1E, ISBN 0-662-12662-9, Ottawa, June 1983.

TABLE 1

PROBLEMS	CAUSES		
	INDOOR CONDITIONS	CLIMATE	CONSTRUCTION
Mould and mildew on inside surfaces of exterior walls	• High relative humidity levels	• Cold weather • Driving rain/little sunshine	• Cold interior wall surfaces due to missing insulation or thermal short circuits
Window condensation	• High relative humidity levels	• Cold weather	• Thermal resistance of glazing too low
Basement and crawlspace condensation	• High relative humidity levels	• Cold weather • High water table • Rain	• Poor drainage • Faulty air barrier • Faulty vapour barrier • Improper flashings • Cracked foundation • Blocked drain tile
Attic condensation	• High relative humidity levels • Pressurized interior	• Mild weather/high outside relative humidity/little sunshine OR • Very cold climate	• Poor attic ventilation • Faulty air barrier • Faulty vapour barrier • Increased insulation
Moisture in wall cavities	• High relative humidity levels • Pressurized interior	• Cold weather OR • Driving rain/little sunshine	• Faulty air barrier • Faulty vapour barrier
Siding damage	• High relative humidity levels • Pressurized interior	• Cold weather during spring • Driving rain/little sunshine	• Faulty air barrier • Faulty vapour barrier AND/OR • Faulty rain screen

MOISTURE SOURCES IN HOUSES

by

R.L. Quirouette

INTRODUCTION

If there is a significant amount of moisture produced within a house, a means of removing that moisture must also exist. Normally, water vapour is removed by air change, either by natural air leakage through the building envelope or by mechanical ventilation systems. It can also be removed by the use of dehumidification equipment but residential dehumidifiers have a limited capability for moisture removal during winter. Many of the current problems of high humidity and condensation in houses may be addressed quite effectively by controlling moisture sources rather than by using a dehumidifier or by increasing the air change rate.

MOISTURE BALANCE

To put moisture input into perspective, consider first just how much water is contained in the air of a typical two-storey house, in this case, one of the Mark XI energy research project houses in Orleans, Ontario.[1] This house has a gross inside space volume of 460 cubic metres. If the air in the house were maintained at 30% relative humidity, then the total water content would be 2.6 kilograms or approximately 2.6 litres. If the air were completely saturated, that is, 100% RH, it would then contain 8.7 litres. While this may suggest that the indoor humidity level is an indicator of the amount of moisture coming in, it unfortunately is not. Conditions in a house are rarely static, that is, there is almost always some moisture being added to the indoor spaces and some moisture which is lost by ventilation or air leakage.

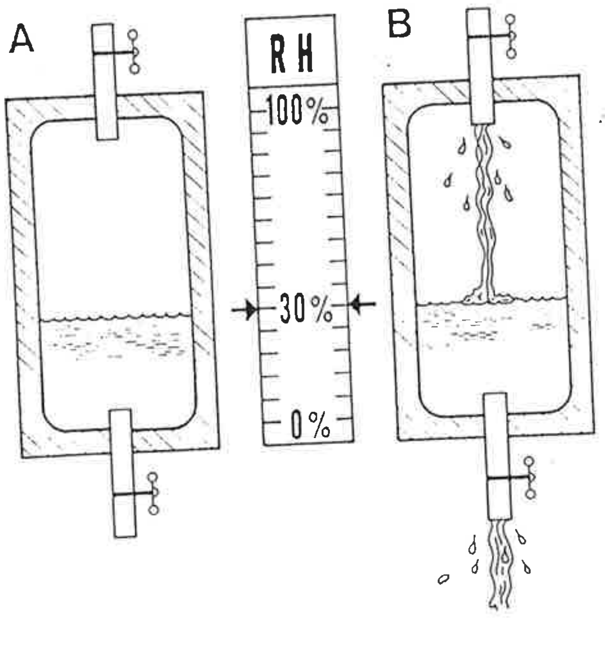


Figure 1

Furthermore, a constant humidity level may be maintained whether the input rate of moisture is high or low. Figure 1 shows two containers which hold water. Imagine that the containers represent the indoor spaces of two houses of equal volume. The extent to which they are filled is the same as the percentage of moisture present in the air of each of these houses.

The first container (A) is filled to 30% of its capacity. This situation parallels what was described above, that is, the house contains a fixed quantity of water vapour relative to its capacity and equal to its relative humidity. Container B is also filled to 30% of its capacity, and provided that the quantity of water entering the top of the container is equal to the quantity of water draining out the bottom, then the level of water remains constant, regardless of the rate of moisture input and loss. This is what is meant by moisture balance, that is, if the humidity level of a house is constant, then the moisture coming into the house must be equal to the moisture going out.

HUMIDITY AND VENTILATION

Suppose we want to determine how much ventilation is required to hold the humidity level in a house to 30% during winter. This relation between moisture input and total ventilation can be illustrated on a simple graph (Figure 2). The graph illustrates the relation between moisture input in litres per day, and the air leakage or air change rate in litres per second, and the resulting indoor humidity level for a particular set of outdoor conditions. The outdoor conditions must be known because the air is itself a contributor of moisture to the house.

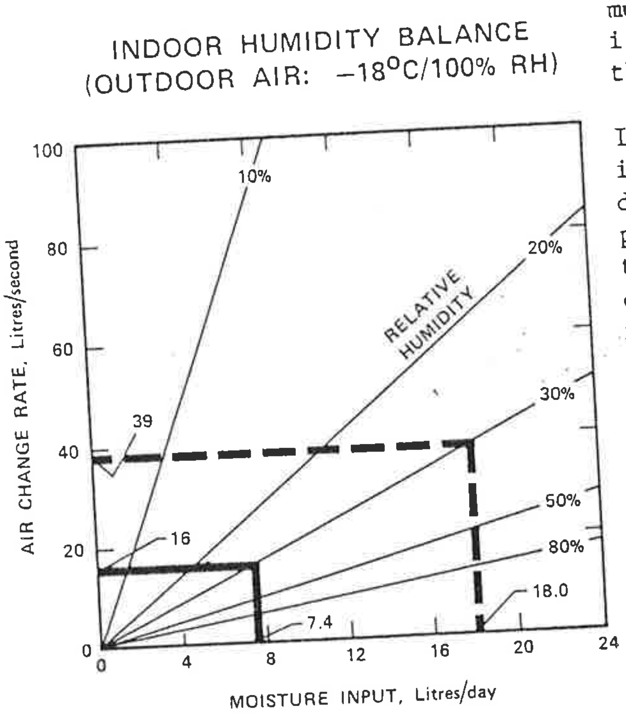


Figure 2

If we assume that the total moisture input to the house is 7.4 litres per day, then 16 litres of outdoor air per second at −18°C will be required to maintain the RH at 30%. On the other hand, if the total moisture input is 18 litres of water per day, then an air change rate of 39 litres per second will be required to maintain the indoor humidity level at the same 30% relative humidity.

Thus, the indoor humidity level of a house is a function of the moisture sources on the one hand, the ventilation on the other, and the rates of each. Simply put, it means that you cannot determine what ventilation rate is required unless you know the total moisture input to any house.

Since ventilation is described in one of the later papers, this paper will examine the various sources of moisture which must be considered for control of the humidity level of houses.

SOURCES OF MOISTURE

There are many sources of moisture which can produce water vapour in a house. Among these are humidifiers, people and their activities, construction materials, basements and crawlspaces, the seasonal storage effect and rain penetration. Each of these is independent of the others, that is, moisture from one source, such as the occupant, has no link to moisture from the basement and vice versa. But all these sources have a direct influence on the moisture balance of the house.

Humidifiers

There are many types of residential humidifiers.[2] These may be classed as humidifiers for central air systems and those for non-ducted applications, the portable humidifiers. Those used for central air systems include the pan type, the most common type of system for oil and gas as well as electric furnaces, the wetted pad type, sometimes referred to as the power humidifier, and the atomizing type, which is not frequently used.

Free-standing or portable humidifiers may employ any of the previously described means of evaporation, however, the wetted pad and blower fan are quite popular. The moisture output rates of humidifiers vary with the model and the make, the location, as well as the indoor temperature and humidity, and the air movement in the room. However, regardless of the type and size, when there is a high humidity problem in a house, one must search for a humidifier and shut it off.

People and their activities

It is commonly thought that household occupants and their activities are generally the cause of high humidities and thus the cause of many condensation problems. There is no doubt that, in some cases, this may be true; however, recent findings from a major study undertaken by Canada Mortgage and Housing Corporation suggest that this is the exception rather than the rule.[3]

In another project done some years ago, household occupancy was studied to determine the moisture production by people and the input rate of moisture for several types of household activities.[4] Consideration was given to the activities of a family of four; it was found that although the activities of the residents may vary, the amount of water vapour produced by metabolic processes such as respiration and perspiration will average about 0.2 litres per hour or five litres per day. This is 1.25 litres per person per day.

A number of activities were also investigated including bathing, showering, cooking, clothes washing and drying, and floor washing (Figure 3). Each of these activities contributes moisture, however, the average increase in moisture input was 2.4 litres per day over the five litres contributed by the occupants.

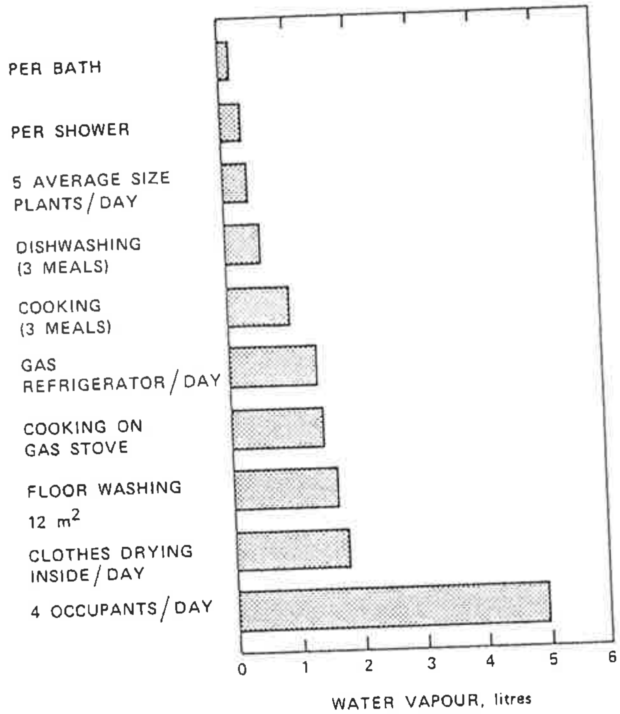


Figure 3

There are four other sources of moisture that are linked to today's lifestyle and are worth noting. These are the use of unvented gas appliances, the indoor garden, baths, saunas and hot tubs, and the use of firewood.

Gas appliances

In the study previously mentioned, it was also reported that unvented gas appliances released moisture. The gas refrigerator, for example, was found to release 1.3 litres of moisture per day. The kerosene heater also gives up a significant amount of water vapour. Its contribution, however, is better related to fuel consumption. The amount of water released by a kerosene heater is slightly more than one litre per kilogram of fuel consumed. Similar rates can be assumed for natural gas and propane.

House plants

The watering of plants and their subsequent emission of moisture was also studied and it was found that plants in general release about 0.5 litres of water per average size plant per week. If the household has a greenhouse with 25 to 30 plants, this may release about two litres of water per day.

Baths, saunas and hot tubs

A recent social trend in new and existing households is to add recreational facilities such as whirlpool baths, saunas, and hot tubs. All these devices generate and release moisture inside a house. Hot tubs in particular should definitely be covered when they are not in use.

Firewood

With the era of energy conservation, there has been a revival of the wood stove. One cord of soft wood brought into a basement to dry would release about 130 litres of water with a 10% change in the moisture content of the firewood. The same cord in hardwood lumber is approximately twice as heavy, and would release more than 250 litres per cord. Considering that a typical house may use about three cords or nine face cords, the total moisture release may approach 800 litres during the course of a winter. If the heating season lasts six months, then it may be assumed that the firewood is releasing moisture at a rate of approximately five litres per day.

THE PARADOX

When one examines the total moisture input by a family of four and their activities, it is interesting to note that few sources contribute as much as the occupant. If all of these moisture-producing activities were to occur in the same day, and included clothes drying indoors, floor washing, cooking, and the drying of firewood, the combined load would approach 18 to 20 litres per day.

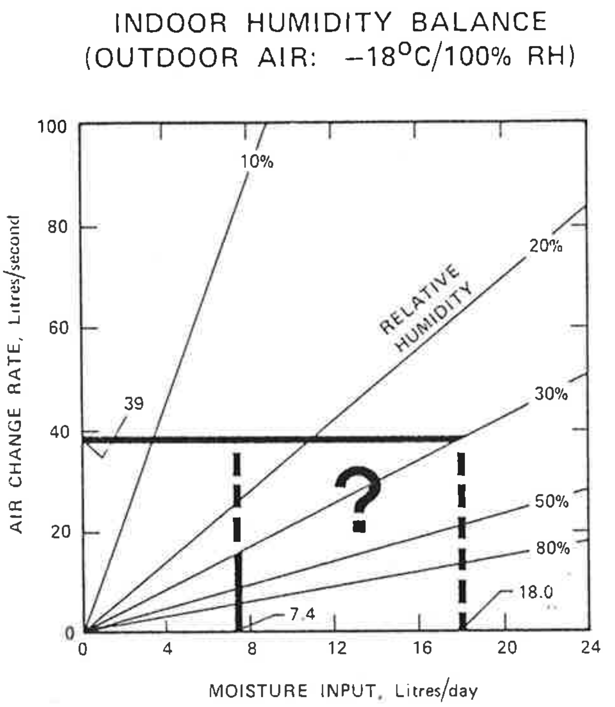


Figure 4

When we consider even an above normal moisture input rate from an occupancy and equate this to the average ventilation (Figure 4), we are left with a significant gap between the average air exchange rate of the house and the average occupancy moisture input. These simply do not equal a high humidity condition.

It means one of two things. The assumed natural ventilation rate of the problem house is considerably lower than the average, that is, it is an airtight building, or the occupant contributes only a portion of the total moisture input and there are other sources to consider. It is quite likely to be a measure of both, as recent field investigations have already begun to reveal. However, since airtightness and low air change rates are well discussed in the following articles, we will focus here on the many "hidden" sources of moisture which affect the indoor condition of any house.

CONSTRUCTION MOISTURE

The typical house is constructed from lumber that is usually quite wet, concrete, which requires substantial water in its fabrication, and numerous other products including sheathing, insulation, air and vapour barriers and cladding materials. Concrete and lumber may contribute significant amounts of moisture after completion of construction.

Framing lumber

Using the same two-storey Mark XI house, it has been calculated that the total weight of framing lumber used to construct the partition walls and all floor joists of the first and second floor would be about 2100 kilograms. If the lumber used in the construction had a moisture content of 19% (and this would not be unusual), and if it eventually dried out to 9% moisture content, it would release over 200 litres of moisture. This moisture is given off to the interior of the house and mixed with other sources of moisture.

Concrete foundations

Most new houses are built on concrete foundations. Assuming that the foundation of the sample house is approximately 2.5 metres high, and 0.25 metres thick, and that it has 35 metres of perimeter wall, the foundation would contain 22 cubic metres of concrete. The basement floor contains about four cubic meters of concrete, for a total of 26 cubic metres. In a general mix of concrete, one cubic metre requires 210 litres of water or more during the mix, but with hydration, eventually retains slightly less than 120 litres of water. This concrete therefore releases 2340 litres of water during the curing process. This water would be released within the first two years and probably most of it within the first year.

When lumber and concrete are drying they may contribute from 2000 to 3000 litres of water to the indoor space, depending on the size of the building, the moisture content of the framing lumber and the surface area of the concrete which is exposed. Assuming an 18 month drying period, this represents from four to five litres of moisture per day, a significant contribution compared to the occupancy-generated moisture. It is not surprising therefore, that many complaints of high humidity and condensation problems appear in the first two years after construction.

SEASONAL STORAGE OF MOISTURE

There is another phenomenon which can augment the moisture input rate during the condensation season. This is the cyclical storage and release of moisture from furnishings and various construction materials inside the house. Given that most houses are vented in the summer, the warm humid air from the outside will impose a high water vapour pressure on all materials inside the house. Including some rainy days when the outside humidity is near 100%, the outdoor humidity level may very well hover in the range of 60 to 90% for several months during the summer. Thus with ventilation, it is quite likely that the indoor conditions of the house will also be at fairly high humidities, but because of the warm summer temperatures, there will be little or no condensation occurring anywhere within the building envelope except perhaps on cold surfaces in a basement. However considerable moisture may be stored within the building structure.

When winter conditions arrive, the indoor humidities will be much lower. This is because air leakage and ventilation carry away most of the indoor moisture, leaving a humidity level which is usually in the 30 to 40% range; this can cause much of the hidden moisture to reappear in the indoor air.

Framing lumber, plywood, furnishings

If the outdoor humidity during summer were around 75%, then the moisture contents of cellulose and wood furnishings would increase up to 11% (Figure 5). In comparison to this, if the indoor humidity were lowered to 30% during winter, then materials and furnishings would tend to give up the stored moisture and try to reach a new equilibrium moisture content (at about 6%). This is a 5% change in weight and would release 105 litres of water vapour during the winter period. This stored water would be released at a rate of about 0.9 litres of water per day, assuming a four-month decay period until spring and summer conditions arrive once more.

EQUILIBRIUM MOISTURE CONTENT OF WOOD AND CONCRETE

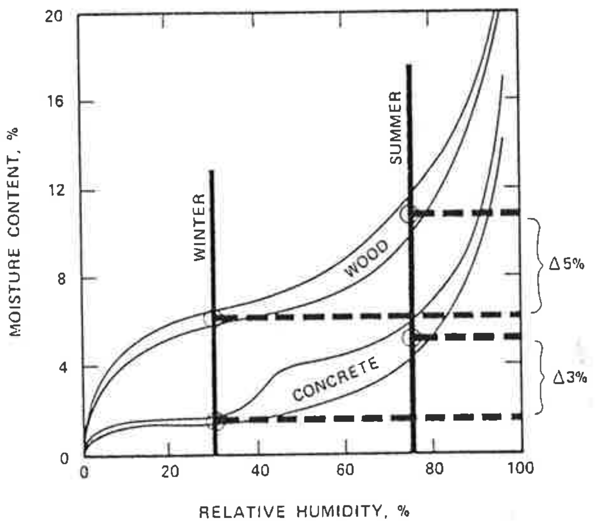


Figure 5

Concrete surfaces

Concrete behaves somewhat like wood, except that its percentage change in moisture content is slightly less for a given change in humidity level. However, it may be more important, because the total weight of concrete far exceeds the total weight of lumber in a typical small house.

From our previous example, it was determined that the two-storey house had about 26 cubic metres of concrete. While Figure 5 shows a potential change of about 3% from summer to winter, even a 1% change will have a significant impact on the moisture balance of a house. Twenty-six cubic metres of concrete may absorb as much as 600 litres of water during the summer (1% change in weight) to be released again in winter at the rate of about five litres per day. Again, this is not an insignificant amount when compared to the occupancy-generated input.

Combining the moisture released from the lumber, gypsum, furniture and concrete of a house, these sources are releasing from three to eight litres of water per day from seasonal storage only. The rate will, of course, depend on many factors, but the most significant are the temperature and humidity levels of the summer for a particular geographic location and the exposure of wood or cellulose products and concrete within the house.

Seasonal moisture storage and seasonal release of moisture are not quite linear. In fact, a substantial portion of the stored moisture is released rather quickly in early fall, when the outdoor temperatures and indoor humidities are falling rapidly. This is the usual cause for condensation complaints around this time.

BASEMENTS AND CRAWLSPACES

A house basement should be compared to a warm sponge on wet ground. Many of the more serious moisture entry problems appear in the basement. Moisture enters the basement by diffusion, by the capillary action of water, by air leakage through block walls and through cracks and joints of concrete walls and floors, and by flooding and water drainage problems.

Concrete walls, even after lengthy years of drying, emit moisture to the inside by the process of diffusion, whereby water vapour migrates through the concrete from a wet condition on one side to a drier condition on the other. A DBR research project that is still in progress has investigated a few house basements and it appears that two to three litres of moisture per day may be diffusing inward through the basement walls and floor of an average size house. This will depend on the time of the year and the degree of wetness surrounding the concrete surface, as well as the height of the water table below the basement floor.

If a concrete floor slab is partly resting on water, the water may move up through the concrete by capillary action to the near surface of the floor. This could be within three to five millimetres of the floor surface. From this point, the water will vaporize and diffuse with little resistance the rest of the way.

During a recent investigation of a high humidity problem in a brand new bungalow, a plywood subfloor over a basement slab was found to be near saturation less than one year after construction. The plywood floor had become a large evaporative surface, to cause a high humidity condition in the house. The humidity level had been recorded at 50 to 60% during the months of February-March of 1983 and produced much condensation on the windows. It was eventually found that the perimeter drain tile system was blocked at the sump pump pit. After clearing of the blockage, water gushed into the pit from under the floor slab at about six gallons per minute for nearly six hours. A follow-up check (one year later) revealed that the problem has since cleared up.

Concrete blocks are particularly good conductors of moisture because of the greater concrete pore size and the hollow core structure of the block. When a concrete block wall is visibly wet for several feet above the basement floor all around the perimeter of an average size basement, there may be as much as eight to ten litres of moisture evaporating from this surface area per day if the indoor humidity conditions are maintained at 40% or less. If there is any visible water on the floor near the wall, this rate will be substantially increased.

Crawlspaces are another important source of moisture. If the ground surface of a crawlspace is exposed, it may release as much as 40 to 50 litres of moisture per day. If the air in the crawlspace is allowed to find its way to the inside of the house, it can result in serious condensation damage to many surfaces and, in particular, find its way to attics and roof spaces. It's important to maintain crawlspaces covered with a suitable vapour barrier such as plastic film, roll roofing and preferably a screed concrete slab wherever possible.

For the unfortunate tenant or resident who has a flooded basement, 60 square metres of exposed water at five to ten degrees Celsius lower than the ambient air temperature would vapourize at the rate of six litres per hour, assuming that the air above were vented rapidly enough to maintain humidities below 40%. The ventilation required is about five air changes per hour during a typical winter period. In such cases however, the rate of evaporation is offset by higher humidity levels in the house and it usually results in serious condensation problems and damage of all types.

Not so obvious, but of some importance, is air leakage into the basement from around the basement floor perimeter wall joints, through cracks, and around drains. This air may also contain a significant amount of moisture. The moisture input rate would be at a maximum during the coldest part of winter.

This was found during a study of radon gas emissions in basement areas. Under a low pressure difference of ten pascals, water vapour was entering the basement along with radon gas, in the leakage air. During the winter, when a stack effect is at work, the basement area would be under a slight negative pressure with respect to the outside. Thus, outside air may seep down through the soil or around the exterior part of the foundation through window wells, or by drain pipes from eavestroughs to find its way into the perimeter drain tile, become wet, and enter the basement as cold but saturated air. If this finding is generalized, saturated cold moist air could be trickling into the house all winter long.

RAIN PENETRATION

Rain penetration is an age-old problem. However, it is still as mysterious as ever and we are not certain that moisture problems in wall cavities are due exclusively to condensation of moist air leaking out and not from rain penetration.

When rain water appears on the inside of a room it is generally a sign of a much larger problem. Because most walls are constructed with the interior cavities flashed to the outside, most rain which penetrates the cladding should be drained to the outside. But is it? Following a long rainfall, moisture may be retained in various pockets, and may soak many parts of the building envelope.

Depending on the direction of the prevailing wind and the outside temperature, moisture in rain-soaked walls may saturate infiltration air;

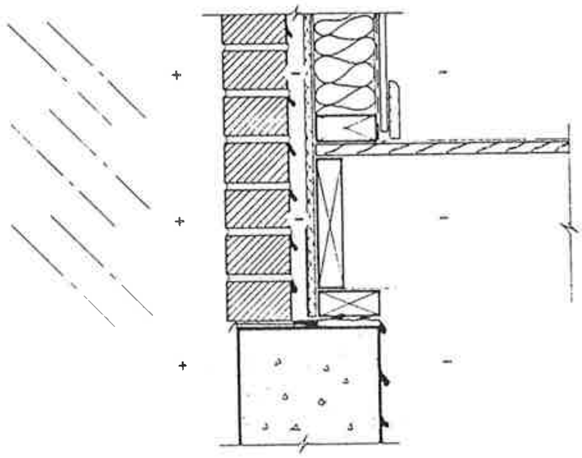


Figure 6

this generally occurs near the foundation wall junction (Figure 6), and may occur even if there is no wind. Stack effect, although not strong, will cause air to infiltrate at the lower portions of the building and in the process, unsaturated cold air will become saturated, thus bringing small but perhaps significant amounts of moisture into the building.

In an experiment which was conducted just recently to verify the use of water vapour as a tracer gas for measuring air change rates,[5] a fan was used to pressurize a small building (Figure 7a). The fan was adjusted to a rate of approximately 60 L/s. The humidifiers that were used to maintain the indoor humidity at 40% responded appropriately by injecting 1.2 kilograms of water per hour to sustain the humidity level. However, when the fan system was reversed, that is, in a depressurization mode (Figure 7b), the humidifiers were not called upon to moisturize the air. Yet, the humidity level remained constant at about 40% during a six-hour test period.

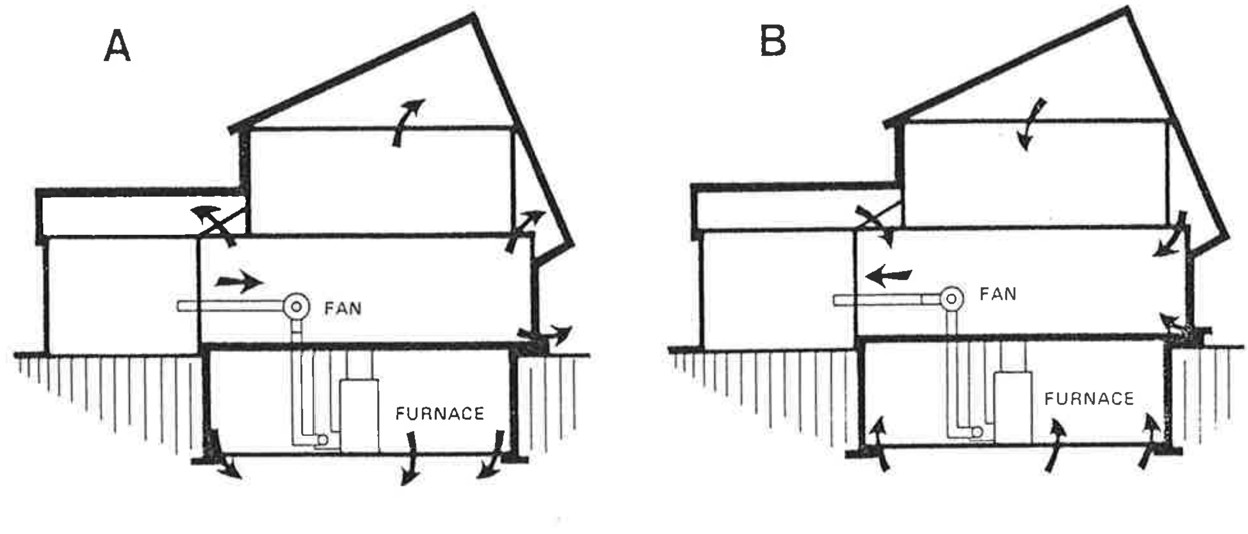


Figure 7

The only reasonable conclusion was that although outside air was being drawn into the house, an equivalent 1.2 kilograms per hour of moisture must have been supplied from the structure (i.e. wet walls) and perhaps from the basement area.

The rain screen

Rain penetration control is the objective of the rain screen. However, recent investigations of the performance of the rain screen suggest that very few wall design and construction techniques actually produce a proper rain screen. The rain screen must be considered as a system and not merely as a vented cladding. The cavity behind the cladding has a very important function in relation to rain screen performance. For the rain screen to be pressure-equalized, the cavity pressure must rise or fall with the wind pressure on the face of the building. To obtain a pressure-equalized cladding, the surfaces and the materials which define the cavity must be airtight and as rigid as possible, so that the cavity volume remains as stable as possible. The cavities behind the cladding must also be appropriately compartmentalized around the building.

If a rain screen wall system has a cavity behind the cladding that connects all around the outside of the building (Figure 8a), then even if the inner wall is airtight, and regardless of the number and size of vents in the cladding, it may still be subject to severe wetting and a significant accumulation of rain in the cavity. This is because the wind-induced negative air pressures on two or three elevations of the house induce a negative pressure in the cavity. This results in a large pressure difference on the cladding of the windward side and forces rain directly through the cladding into the cavity. If the inner wall is airtight then the air and water penetrating the cladding to the cavity would deposit the moisture in the cavity, while allowing the air to circulate and exhaust from openings on the leeward side. If however, the air finds a passage through the inner wall, water may penetrate directly to the inside with the infiltrating air. The need for near-perfect airtightness of the wall cannot be overemphasized but compartmentalization is also a necessary component of the rain screen principle (Figure 8b).

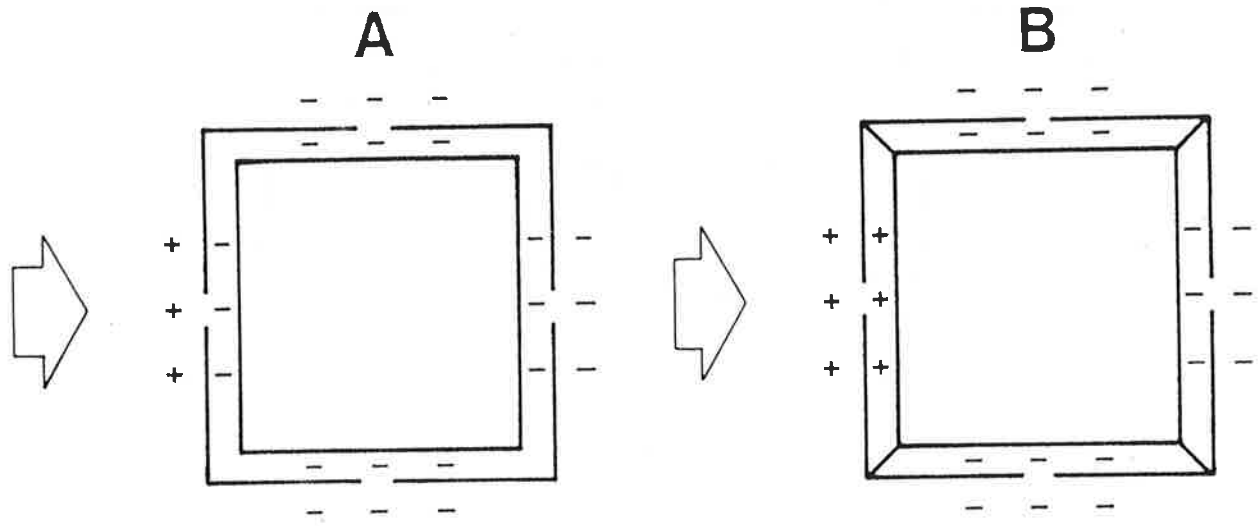


Figure 8

Rain penetration through a cladding may never be stopped entirely, however, if greater care were taken with flashing detail, and more importantly with airtightness, rainwater penetration through a wall would be reduced.

SUMMARY

When all the various sources of moisture are considered, the total moisture input in a house is a combination of that contributed by the occupant and his activities, but also from a number of less obvious sources such as construction moisture, the seasonal storage effect, basements or crawlspaces and rain-soaked walls.

High humidity conditions and excessive condensation appearing in a house are caused by the total moisture input from all sources, but those sources not contributed by the occupants should be corrected first before deciding that extra ventilation is the only way to lower or control the indoor humidity level during winter.

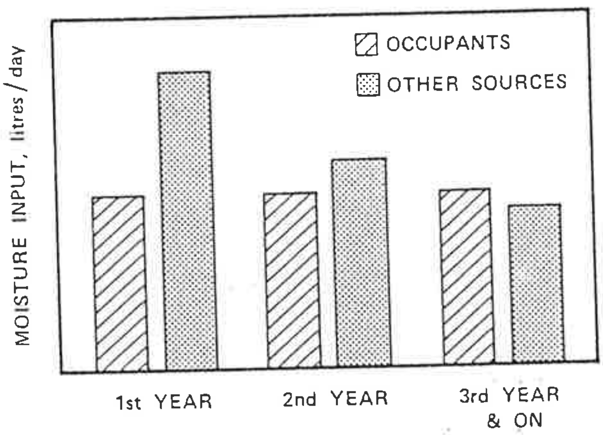


Figure 9

Finally, when considering the probable moisture input rate in a new house, the following guide is suggested to a probable moisture load for the first, second and subsequent years of operation of a typical new house (Figure 9). In the first year, the total moisture input from occupants and other sources may average 20 or more litres per day during winter. As the building materials dry out, the total moisture input rate may drop to 15 litres per day during the second year and settle eventually to a rate of about ten litres per day in the third and subsequent years.

Hence from a third to half of the total input of moisture is generated by sources other than the occupant and his activities. It is not practical to suggest that the occupant lifestyle has to change, except in special circumstances, but it is feasible, and it will be necessary to address the many other sources of moisture to control humidity levels in new as well as retrofitted houses.

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CONTROL OF SURFACE AND CONCEALED CONDENSATION

by

Madeleine Z. Rousseau

INTRODUCTION

Condensation in houses is a controversial and complicated issue. Over the last ten years, it has taken on new dimensions because of the changes in building practice. For example, Canadian houses are better insulated and this affects the temperature regime of the building envelope; outside and inside surfaces of walls are subject to colder and warmer temperatures, respectively. Therefore, the potential for surface condensation inside the house is reduced, while the potential for concealed condensation in the wall and ceiling cavities is increased. Moreover, houses today are more airtight, which often results in higher humidity levels; this in turn may lead to increased surface condensation, particularly on windows. This paper discusses the mechanisms of condensation: how, where and why condensation occurs on walls, windows and basement surfaces, as well as within walls, windows and attics.

SURFACE CONDENSATION

Surface condensation is the phenomenon by which moisture condenses on visible surfaces. It occurs on surfaces that are at a temperature below the dew point temperature of the inside air. In the wintertime, surface condensation is most common on windows and window frames, over the gypsum board face at or near the stud connection of the walls, on floors and at wall corners.

When moist inside air is cooled, a temperature is reached at which the air becomes saturated with moisture. This is the dew point temperature of the inside air. If the surrounding surfaces continue to cool, the moisture in the air condenses on the surfaces as a liquid or as frost, if the surface temperature falls below freezing. Therefore, three factors are involved in the surface condensation process: the inside air temperature, the indoor humidity level, and the surface temperature. The latter is a function of the outside temperature and the thermal resistance of the assembly. The interaction of these factors is best explained on a psychrometric chart. (See page 64 for detailed version of psychrometric chart.)

Psychrometrics

The psychrometric chart is used to describe the physical characteristics of air and water vapour over a broad range of temperatures (Figure 1). The vertical scale represents the absolute moisture content, defined as the number of kilograms of moisture per kilogram of dry air. The horizontal scale is the air temperature, scaled from -10 to +55°C. The saturation curve (100% RH curve or dew point curve) shows the maximum amount of moisture that the air can hold at any temperature in this range. The higher the temperature, the more moisture the air can hold. For example, air at 23°C can hold six times as much water vapour as air at −5°C (Figure 2). The other curves are the relative humidity curves, and represent a fraction of the saturation point. The 50% RH curve means that at this curve the air holds half of the amount of moisture it could potentially hold (Figure 3). This chart is often used to calculate the dew point temperature of the inside air; from this one can calculate the required thermal resistance of an assembly (such as a window) to prevent or avoid condensation on its surface.

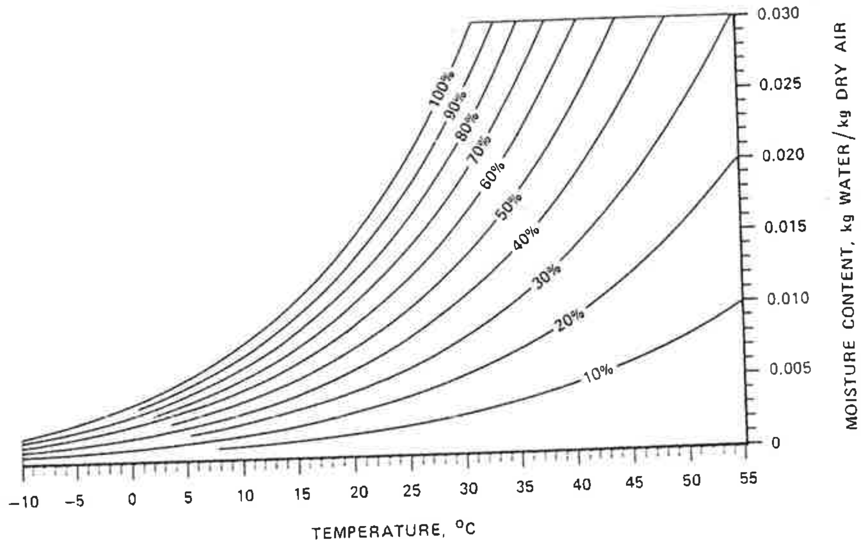


Figure 1

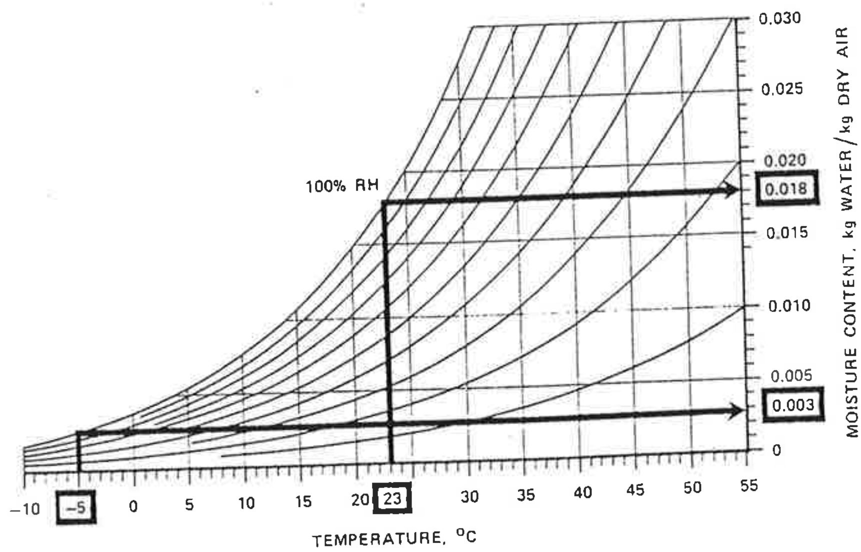


Figure 2

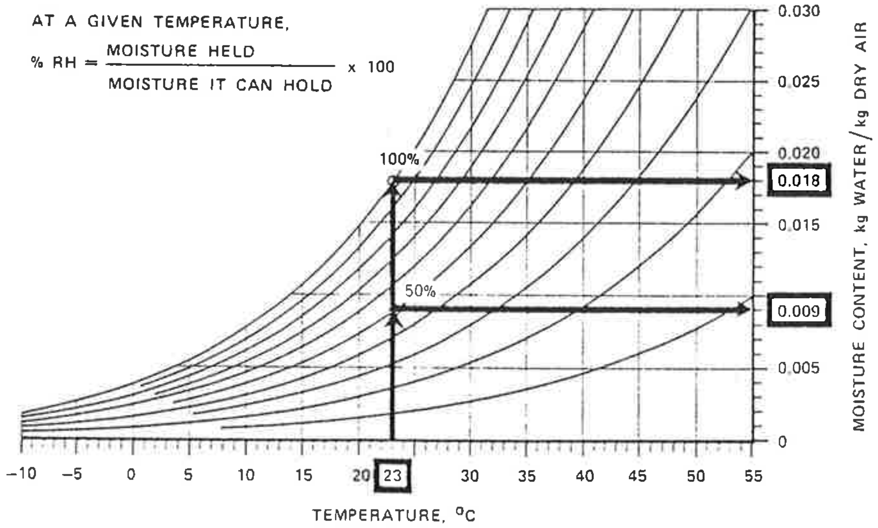


Figure 3

For example, suppose that the inside air in a room is at 23°C and 50% RH; what would be the dew point temperature of the air? First, plot the intersection of the inside air temperature with the measured relative humidity (Figure 4). Second, move horizontally to the left until you intersect the 100% RH curve. Third, plot the intersection downward until it intersects the temperature axis once more, at about 12°C. This is the dew point temperature of the inside air. Therefore, if condensation appears on the surface of window glass, then the temperature of the glass must be below 12°C.

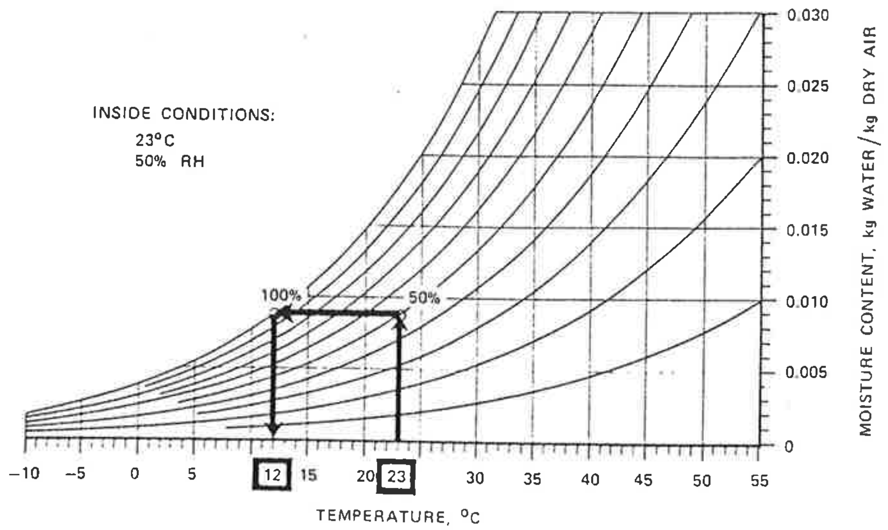


Figure 4

Summer condensation in basements

Condensation may also occur in the summertime on basement floors, especially if the basement space is ventilated. Outside air has a high moisture content during warm weather and the dew point temperature of the air may also be relatively high. Basement floors, which are most often uninsulated, may easily be colder than the dew point of the outside air.

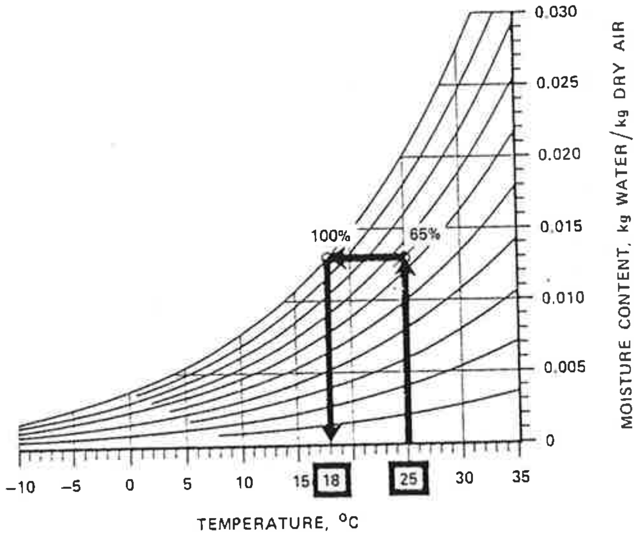


Figure 5

For example, it can be shown on the psychrometric chart (Figure 5) that if the outside air is at 25°C and 65% RH, the dew point temperature of the air is 18°C. Condensation will occur on the concrete floor surface or concrete foundation wall if the surface temperature is below the dew point temperature.

Surface condensation is caused either by a low surface temperature or a high humidity level in the air. The solution is either to increase the thermal resistance of an assembly to increase its surface temperature, or to reduce the humidity level in the house. The thermal resistance of a window may be increased by adding a pane or two; the humidity level in the house may be reduced by increasing the ventilation rate during winter or reducing the number of moisture sources.

If condensation occurs on basement walls during the summer or winter, it may be most practical to insulate the basement foundation wall so as to prevent the warm humid air from reaching the cold concrete. This will also reduce energy loss through the foundation walls. However, if condensation occurs on the basement floor during summer, it may be more practical to dehumidify the basement air.

CONCEALED CONDENSATION

Damage such as the rotting of exterior sheathing or structural members, the buckling of cladding, spalling and efflorescence on brick and concrete walls, peeling of exterior paint, and condensation between window panes, is mostly due to the presence of water in a cavity. The occurrence of concealed condensation requires three conditions: a moderately high humidity level, moisture movement into a cavity, and a surface which is below the dew point temperature of the inside air. The movement of moisture into a cavity may occur by diffusion through the materials of the wall or ceiling, or by air leakage through holes and cracks presenting an unobstructed path from inside to outside.

Diffusion

Diffusion is the movement of moisture through a building material from a location of high moisture content towards a location of lower moisture content. The diffusion rate is a function of the permeability of the material to water vapour (Figure 6). It is almost always outward in winter. Movement of moisture by diffusion occurs without any flow of air and is a very slow process.

Water vapour diffusion may be compared to water seeping through the surface of a cardboard container (Figure 7). Water permeates slowly and uniformly through the cardboard container surface. The solution is to use a much less porous material, such as plastic or metal. This approach is also used in building construction to control diffusion of water vapour through walls and roofs.

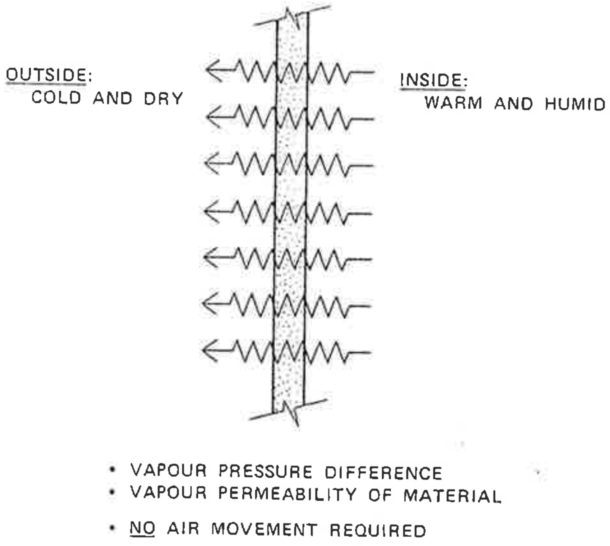


Figure 6

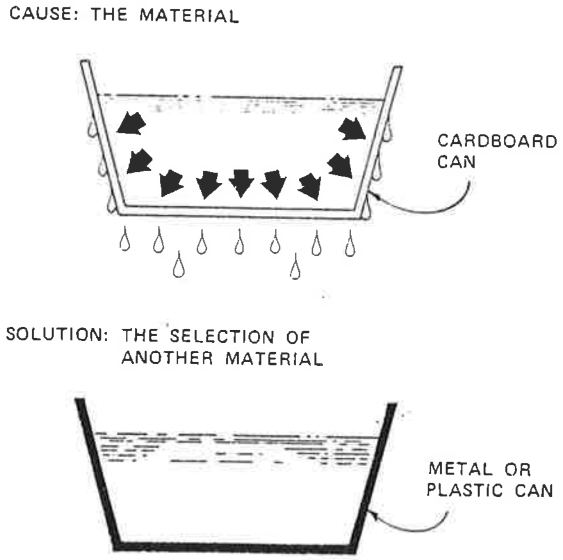


Figure 7

Since it is necessary to maintain indoor humidity at a high enough level for health and comfort, there will inevitably be a humidity difference causing a migration of water vapour from inside the house to the outside. The simplest way to reduce or control the diffusion rate of water vapour into walls and roofs is to choose materials which have a low permeability to water vapour transfer. This material should be placed on the warm side of the insulation, where the water is still in the vapour phase. The material is called a vapour barrier or a vapour retarder.

Examples of vapour barriers are polyethylene film and aluminum foil; there are also several types of paints that could be used as vapour retarders. Their importance in an assembly is well recognized and their required properties are known. The installation of a vapour barrier in a wall assembly practically eliminates the potential for condensation to occur in cavities by diffusion only.

Air leakage

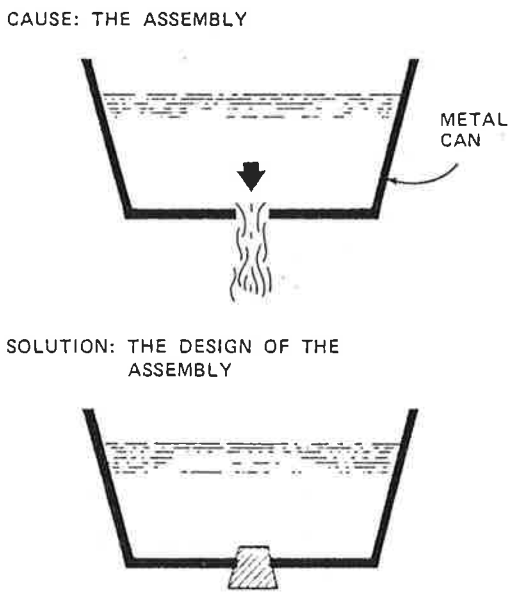


Figure 8

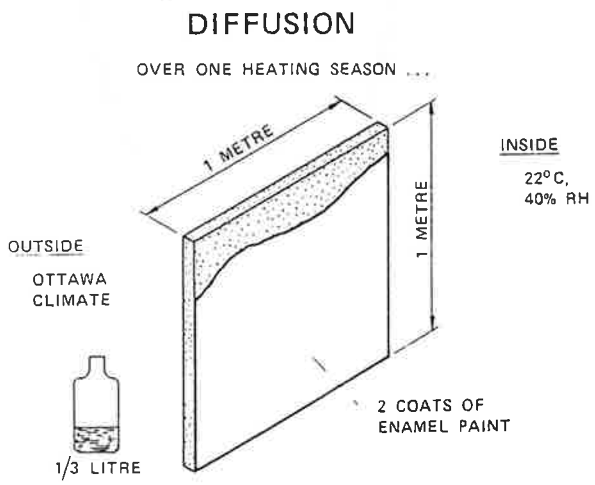


Figure 9

Moist warm air can also flow to the cavity of a wall or ceiling by air exfiltration. Air leakage through an assembly of materials occurs when there are cracks and holes within the assembly and an air pressure difference across the hole or crack. The air leakage rate is a function of the number and size of the holes and the air pressure difference acting across these openings. Air can leak around windows and doors, at chimneys, through holes for electrical wires, and at electrical outlets, just to name a few places.

Using the previous example of a container filled with water, air leakage is similar in principle to a water leak (Figure 8). Whether the material is cardboard or metal will be irrelevant if the container has a sizeable hole in it. The solution is to seal all leaks and holes. Similarly, a building enclosure must be devoid of all leaks, cracks or openings, if air leakage is to be controlled.

Moisture transport into cavities - diffusion versus air leakage

The potential transport of water vapour into cavities by diffusion and air leakage can be compared by an example. Given a square metre of gypsum board with two coats of enamel paint, exposed to 22°C and 40% RH on the warm side and a mean daily outside winter condition for Ottawa on the other side (Figure 9), 1/3 of a litre of water vapour would diffuse over a five-month period.

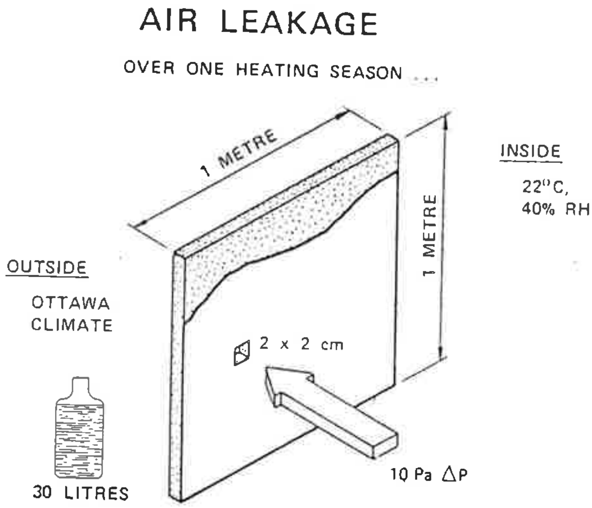


Figure 10

Through a four centimeter square opening, it is possible to pass about 30 litres of water vapour to the outside if a ten pascal air pressure difference exists across the gypsum board (Figure 10). The air leakage process can transport 100 times as much water as that which is transported by diffusion through the one metre square board. Therefore, air leakage through the enclosure is the major mechanism of moisture transfer into cavities.

CONTROL OF AIR LEAKAGE

Air leakage may be considered as either air infiltration or air exfiltration. Since concealed condensation is due primarily to air exfiltration, the emphasis here will be on air exfiltration control. There are two ways to control air exfiltration: the first is to control the direction of air flow and the second is to minimize the number and size of holes. To induce an inward flow of air, the indoor air pressure must be rendered slightly negative with respect to the outside. This will prevent concealed condensation, but this solution is not without its problems. It may also induce an undesirable air infiltration through the walls and ceilings, causing surface condensation (Figure 11), cooling of indoor air and subsequent loss of comfort, low humidity level, and increased heating costs. So, there is only one viable option: to make the building envelope airtight and free of all air leakage.

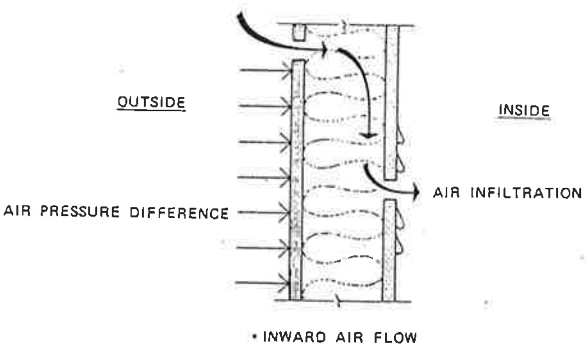


Figure 11

Airtight materials and systems

The system of building materials that will act to stop air movement must also resist the peak air pressure difference that may be induced from a combination of wind load, stack effect and ventilation equipment. Thus, the air leakage control system must also be structural, and rigid, if possible, or if flexible, be supported on both sides. The system must be impermeable to air (not water vapour) and it must form a continuous assembly, designed and built to stay continuous over the life of the building.

Gypsum board, exterior sheathings (e.g. plywood, waferboard), and some types of insulating boards may have the characteristics required. At the present time, no material or assembly of materials is tested for structural adequacy with respect to airtightness and air permeability. However, even without the necessary numbers, it is possible to design and construct a functional airtight assembly within the envelope of a house.

A plastic film that is a good vapour barrier may not be the most appropriate material for an air barrier. A rigid material impermeable to air, like an insulating exterior sheathing, must be mechanically fastened in place, otherwise it can detach and fall into a cavity.

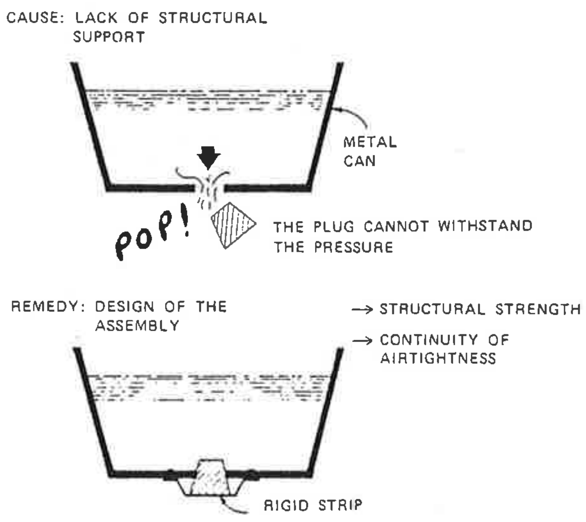


Figure 12

Returning to the example of the leaky container, (Figure 12) merely plugging a hole does not ensure that it will be leak-proof. The plug in the container may only be a short term solution. What is required is a structural support capable of withstanding the pressures that may be exerted on the patch or repair plug.

Depending upon the materials chosen and the design of the wall or roof, there are a number of alternative methods to ensure airtightness and its continuity over the building enclosure. The air sealing method selected should be carried out consistently and throughout the whole of the building enclosure. This means that not only walls and ceilings must follow the principle but it must be carried out consistently at floor-wall, wall-and-partition, and wall-and-ceiling junctions. It may also be necessary to extend an airtightness assembly to below-grade connections to reduce moisture entry by air seeping in through cracks and joints, as mentioned in the previous paper.

WALL AIR LEAKAGE PROBLEMS

Cladding deterioration, efflorescence on brick and rotting of wood members may be due to rain penetration or concealed condensation; either way, air leakage is a major contributing factor. A wall that has a good vapour barrier but no air barrier, may have a localized spot of concealed condensation. Because walls are made up of many layers of materials with cavities between, the flow of air will usually require that there be an entrance to and an exit from the cavity. Thus if air leakage is outward (i.e. exfiltration) the air will follow a particular path from its entry point in the wall to its exit point in the exterior cladding. Condensation of moisture from the air is likely to occur near the end of the path, on a surface that is at a temperature below the dew point temperature of the inside air (Figure 13). The openings are often the large gaps left between exterior sheathing boards or between the window frame and the rough opening, even though it is filled with fibreglass.

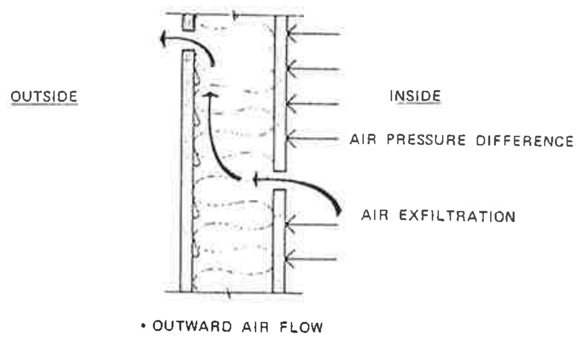


Figure 13

Materials such as exterior sheathings or brick cladding can store water for a while, until the right climatic conditions, such as a sunny day, cause the water to migrate towards the outside. Condensation on a porous surface increases the moisture content of the material. Efflorescence on a brick cladding is due to the migration of water to the outside. As the water migrates to the outside it brings with it calcium salts present in the mortar to deposit them on the surface when the water evaporates. The question is, "how does moisture find its way to the backside of the brick siding?" It may be by rain penetration, but more likely it is inside moisture transported by air leakage through the wall during winter.

Whether the cause is rain penetration or air exfiltration, the solution is to have an air barrier system somewhere within the building enclosure. In fact, an air barrier can be located almost anywhere within the building assembly to control throughflow of air.* If either the inside or the outside skin of a wall is airtight, then the throughflow of air should be under control. Thus, the primary reason for the deposition of moisture in a cavity has been effectively eliminated.

Air barrier inside

When the interior finish is intended to be the wall air barrier (Figure 14), the critical point becomes its continuity over the enclosure. All connections with floors, partition walls, electrical outlets and switches must be made structurally airtight. Airtight boxes should be built around electrical outlets to ensure continuity of the air barrier. The air barrier on the warm side of the enclosure has the advantage of being exposed to relatively stable thermal conditions, but it can be also subjected to numerous penetrations as it is the interior finish. It has a further advantage in that if it is visible, it is also serviceable.

* The apparent contradiction with other recommendations arises from the vagueness of the distinction between the function of a vapour barrier (which is well defined) and that of an air barrier (which is not yet adequately defined).

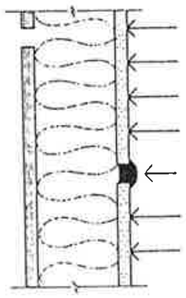


Figure 14

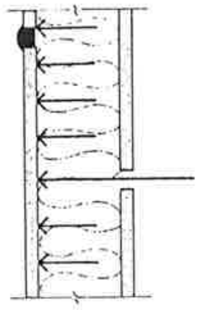


Figure 15

Air barrier outside

When the exterior sheathing is intended to be the air barrier element of the wall (Figure 15), its continuity over the wall and around corners is much easier to achieve from a construction point of view. Most outside structural framing presents a continuous uninterrupted surface over floor connections, partition walls, and exterior corners. It also removes the concern with penetrations of electrical outlet boxes through interior finishes. The materials used for this purpose should be rigid, well supported, air impermeable and fastened directly to the structure. They must be made continuous over the whole wall with appropriate joint connecting materials, and continuous with the ceiling assembly and foundation wall. The materials should have a high water vapour permeability and a low air permeability, for example, gypsum board or dense fibreboard. Depending on the water vapour permeability of the air barrier, it may be necessary to install on the warm side of the insulation a vapour barrier that is considerably less permeable than the sheathing material used for airtightness on the outside of the wall.

In brief there are many ways to install an air barrier in a wall, in order to avoid serious localized moisture damage in wall cavities. Only one surface of a wall needs to be structurally airtight; whether it be inside or outside is not relevant to the control of the throughflow of air. However there must be a good quality vapour barrier on the warm side of the assembly.

CONDENSATION IN ATTICS

Attics may be more prone to harbour condensation because the air pressure difference across a ceiling is often positive and this induces an air exfiltration pattern through cracks and holes.

Moisture transport in an attic is similar to that in other cavities; air leakage is usually the major means of supplying the attic with moisture. When the temperature of the outside sheathing of the roof is below the dew point temperature of the attic air, condensation occurs on its inner surface. The moisture content of the wood increases slowly and the sheathing may deteriorate in a few years.

The location of condensation in an attic is a function of the leakage path from the inlet holes in the ceiling to the outlet holes in the roof. Consider the following example; a bathroom fan is ducted through the attic to exhaust moist stale air through the roof. Often, condensation occurs inside the duct, and water may drip back down into the bathroom. The occupants will then disconnect the duct through the roof (Figure 16) and leave the duct or piping lying on the insulation. A significant amount of moisture is then drawn into the attic by the fan: if there is a ridge vent on the roof, this becomes an important moisture outlet.

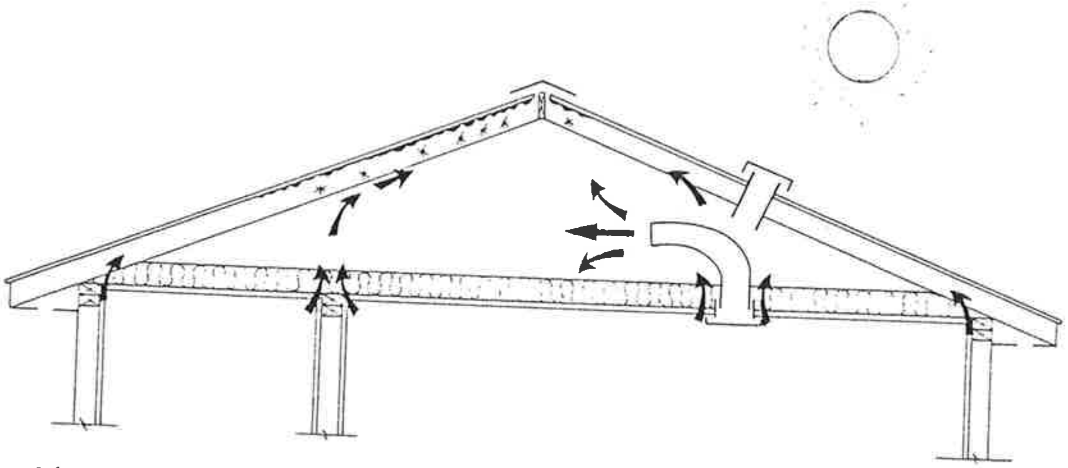


Figure 16

The cold air in the attic cannot absorb much moisture because the outside air is often close to saturation. The building materials on the path of the air stream to the outside may absorb part of the moisture and the condensation pattern is related to this path.

The orientation of the roof also has an effect on the potential for concealed condensation damage. A southern pitch will dry out more quickly during the day than a pitch on a northern exposure. All these factors acting together make every pattern of attic condensation almost unique.

The best way to control an attic condensation problem is to tighten the ceiling and the walls. For example in row houses, moisture can get into attic cavities by seeping through a common concrete block partition wall. In this context, it is of prime importance to properly air seal all paths into the attic. These are not always obvious.

SUMMARY

Surface condensation is either due to a high humidity level or a low surface temperature. It can be controlled by acting on the moisture gains and the ventilation to lower the relative humidity, or by increasing the surface temperatures of those components which exhibit surface condensation.

Concealed condensation is more complex than surface condensation. Moisture can be transported into cavities by diffusion or by air leakage. It has been recognized since the early 60's that air leakage is the major cause of moisture problems in wall and roof enclosures or cavities. Attention to vapour diffusion control has been thorough, but air leakage control is not yet fully understood. It is necessary to have both a vapour barrier and an air barrier within the building envelope to control the diffusion rate of moisture as well as to stop or reduce air leakage through the cavities.

The air barrier has properties which are quite different from those of a vapour barrier. A vapour barrier deals with a difference in water vapour pressure while the air barrier must deal with an air pressure difference (with or without humidity), and resist the forces caused by wind, ventilation and stack effect. A vapour barrier is required in a wall or roof assembly but it is not sufficient to eliminate the moisture problems from cavities.

The precise characteristics of an air barrier are not completely defined as yet, but it must be structurally supported, rigid if possible, or if a flexible membrane, then supported on both sides. Needless to say, the whole assembly must have a low air permeability and be continuous throughout the building enclosure.

VENTILATION OF HOUSES

by

G.O. Handegord

INTRODUCTION

In the past, we have relied on natural forces and unintentional leakage paths in the house envelope to provide ventilation in winter and on the use of exhaust fans or the opening of windows to increase the ventilation rates when required.

In general, the rates of natural ventilation achieved in houses with fuel-fired systems in winter have been adequate for the removal of moisture generated within the house and have also provided a rate of ventilation or air change sufficient to maintain an acceptable level of air quality. The negative pressure created within a house by the exhaust action of the operating chimney has been recognized as an important factor in reducing the amount of condensation occurring within walls or roof spaces. In contrast, houses without chimneys, such as electrically heated houses, have tended to have higher indoor relative humidities and a greater incidence of condensation problems.

When energy conservation became popular, air leakage through the house envelope was singled out as a major energy loss and has received special attention, involving the promotion of airtightening techniques and special construction methods.

This emphasis towards building tighter and tighter houses has raised concerns regarding the adequacy of natural air leakage and ventilation for the health and safety of the occupants. This concern, coupled with a recognition that new contaminants are introduced into residential occupancies through building materials, furnishings and the activities of the occupants, has reinforced the need to provide controlled ventilation systems in houses, as well as special procedures to handle certain contaminants.

This recognition of ventilation requirements for air quality has also focussed attention on possible means of heat recovery from the ventilating air, in order to achieve optimum energy conservation.

This paper reviews the factors influencing air leakage in houses, and the role of air leakage in condensation and ventilation. The requirements for ventilation for air quality and humidity control will be considered as a basis for discussing ventilation systems that might be suitable for Canadian housing, including some suggestions for heat recovery.

AIR LEAKAGE THROUGH THE HOUSE ENVELOPE

The rate of flow of a fluid through any hole or opening is proportional to the cross sectional area of the opening, and the pressure difference (or head) maintained across the opening. The larger the opening, the greater the flow; the higher the pressure difference or head, the higher the rate of flow.

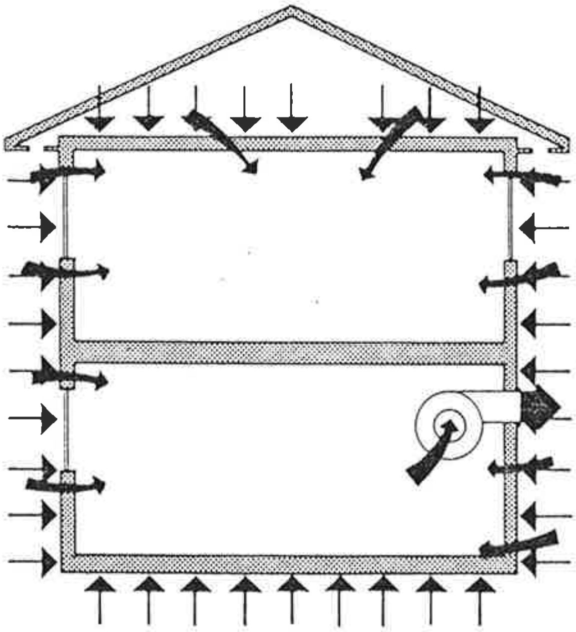


Figure 1

The overall airtightness of the house envelope is thus just one factor in the air leakage equation. The rate of flow, or air change rate, will depend not only on the size and location of the leakage path, but on the magnitude and direction of the pressure difference acting across it.

There has been a growing interest in the use of the depressurization method for estimating the air leakage characteristics of a building envelope. An exhaust air blower pulls air in through all the unintentional leaks in the house envelope and exhausts it to the outside (Figure 1). In this figure, as in subsequent diagrams in this paper, a straight arrow (→) represents air pressure; the wide curving arrows (➡) represent air flow.

Such tests are simply one application of the air leakage equation to calculate the equivalent cross-sectional area representing the total of all the leakage paths in the walls, windows, ceiling and floor of the exterior envelope.

$$\text{(ELA)}\quad \text{equivalent leakage area } (m^2) \simeq \frac{1}{780} \times \frac{\text{rate of flow (L/s)}}{\sqrt{\text{pressure difference (Pa)}}}$$

The most common method for air leakage testing is to use a variable speed, high capacity fan to exhaust air from the house, and to measure the rate of exhaust and the corresponding air pressure difference created across the envelope. The tests are usually undertaken through a range of pressure differences from ten pascals up to fifty pascals or more.

The air flow rate for each pressure difference is plotted to indicate a characteristic curve and the total equivalent leakage area (ELA) is calculated, based on the rate of air flow required to create a particular pressure difference across the building envelope, usually at a pressure difference of ten pascals.

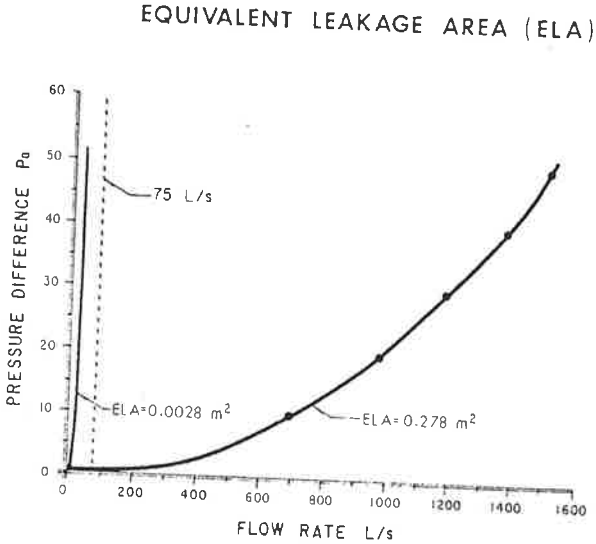


Figure 2

The results from a large number of air leakage tests undertaken on many houses across the country have been summarized by Jim White of CMHC in a recent paper.[1] His data suggest that the equivalent leakage areas for different houses in different regions vary from a low of 28 cm^2 up to 2780 cm^2 or from a total opening size of about 5 × 5 cm up to 50 × 50 cm (Figure 2).

Air leakage due to wind

It is possible to estimate the amount of air leakage that will be due to wind, if a simple two-dimensional model is assumed; such might be the case with a centre house in a row housing unit (Figure 3).

For an average wind velocity of 16 kilometres per hour, an inward-acting pressure of about ten pascals could be created across the windward wall, and an equal but outward-acting pressure might be considered to act across the leeward wall. If equal sized roof vent openings are located on the windward and leeward sides, no sustained pressure difference will be developed by wind across the ceiling, and most or all of the flow will occur inward through the windward wall, with an equal flow outward through the leeward wall.

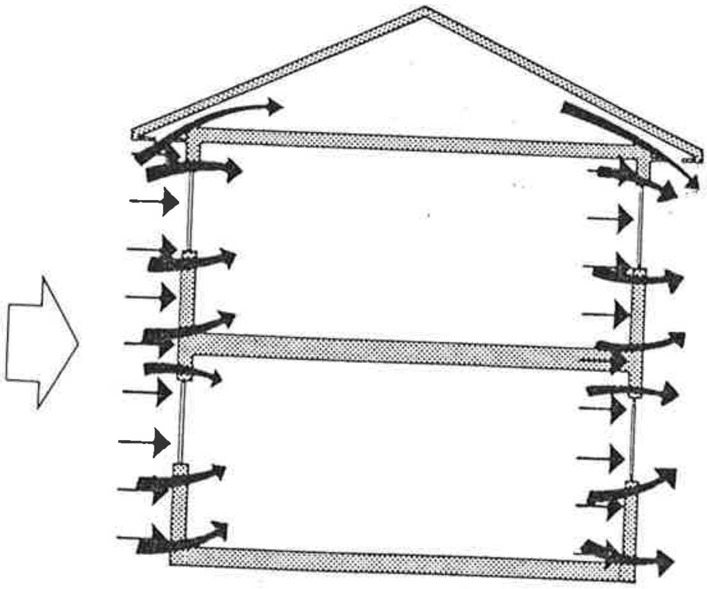


Figure 3

If it is also assumed that leakage openings are uniformly distributed over the wall and ceiling and that the wall and the ceiling are equal in area, an air flow rate of about 1.7 litres per second can be estimated for the tightest house on record, and 170 litres per second for the leakiest house. For a house of average size, these rates correspond to 1/100 of an air change per hour for the tightest house, and one air change per hour for the leakiest house.

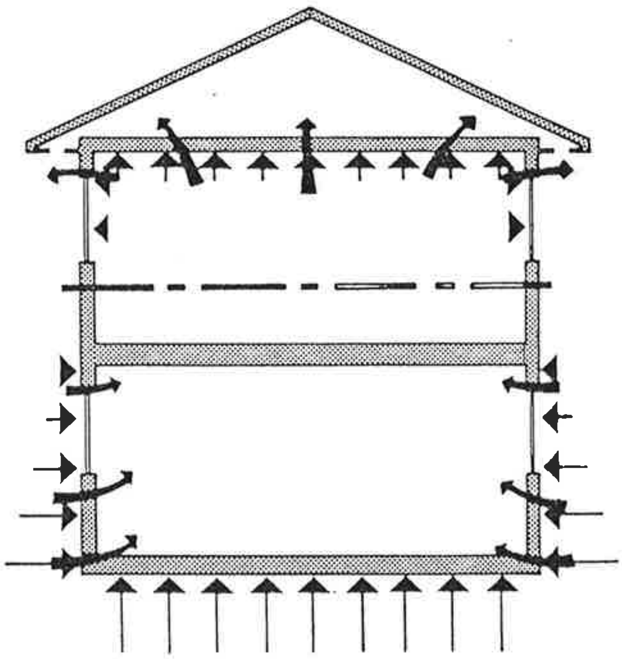


Figure 4

<u>Air leakage due to house stack effect</u>

Natural air leakage will occur because of stack effect whenever the outside temperature is lower than that inside the house (Figure 4). If we again assume that the leakage openings are uniformly distributed throughout the walls and ceiling, a mid-winter stack effect pressure of ten pascals would result in a rate of infiltration of about one litre per second for the tight house and 100 litres per second for the leaky house.

For a house of average size these would be equivalent to an air change rate of 1/160 of an air change per hour for the tightest house and about 2/3 of an air change per hour for the leakiest house.

<u>Air leakage due to chimneys</u>

In houses with fuel-fired heating systems, the stack effect or draft created in the chimney when the heater is operating is much higher than that created by the house, because the temperature within the chimney is much higher. The suction of the chimney in exhausting air and gases from the house (Figure 5), and the negative pressure created at the base of the chimney, will be proportional to the temperature difference between the flue gases and the outside air.

An oil furnace or fireplace could create a theoretical draft of over fifty pascals at -30°C outdoors, and over 35 pascals at an outdoor temperature of 15°C. A gas-fired furnace with a draft hood will operate at a lower flue temperature and, under mild weather conditions, might generate a theoretical draft of 25 to 30 pascals. If there was some restriction to flow of air for draft control, the flue temperature would rise and negative pressures over 30 pascals could theoretically be created under mild winter conditions before spillage occurs.

The rate of flow of air for combustion and draft control up the chimney will vary from a maximum of perhaps 200 litres per second for a fireplace with no doors over the opening, through 70 litres per second for a conventional oil furnace with barometric damper, to five litres per second for an airtight wood stove.

For an average size house, these represent air change rates ranging from 1-1/3 air change per hour for the fireplace, 1/2 air change per hour

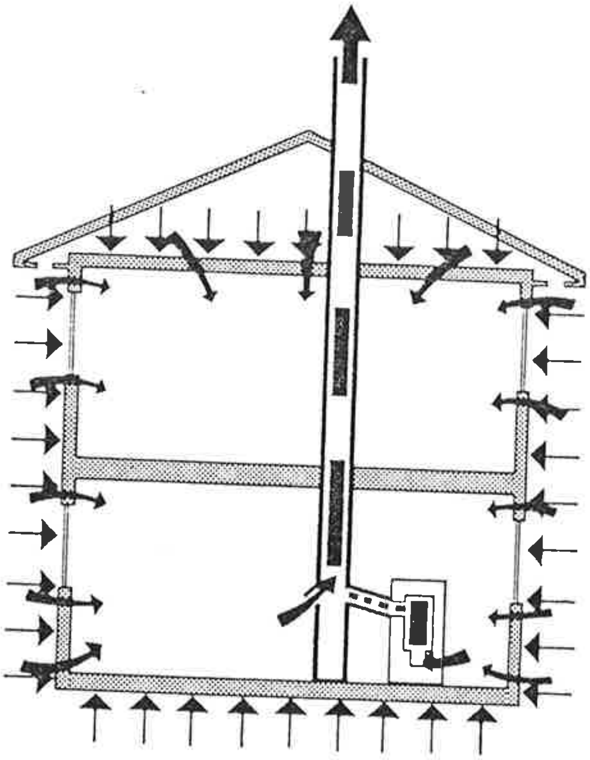


Figure 5

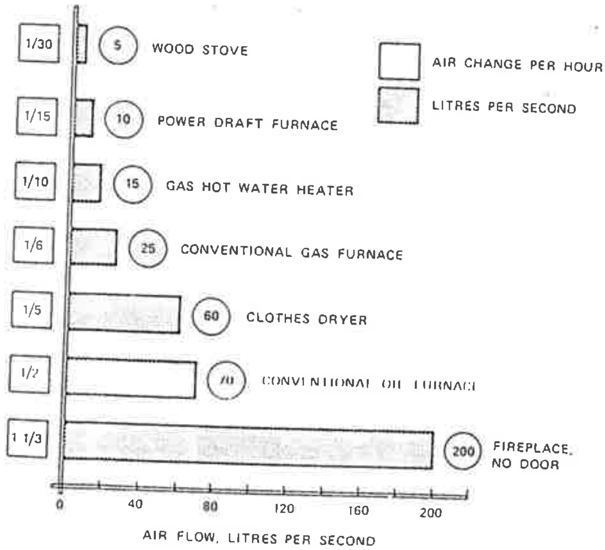


Figure 6

for the oil-fired furnace and 1/30 of an air change per hour for the airtight wood stove (Figure 6). A vented gas or electric clothes dryer will exhaust air at about 60 litres per second, equivalent to 4/10 of an air change per hour. It will create a negative pressure and air leakage pattern similar to an operating chimney.

AIR LEAKAGE AND CONDENSATION IN WALLS AND ROOFS

The amount of outside air leaking into the house is a prime factor in determining the indoor humidity level, but it is the air leaking outward through the house envelope that carries moisture into the colder spaces of the walls and roofs. Moisture flow by diffusion is always outward in winter but moisture may flow either in or out by air leakage.

In a house without an operating chimney or an exhaust fan, the action of wind is to move air inward through the windward wall and outward through the leeward wall with little impact on air movement through the ceiling. One would thus expect that, under the action of wind alone, condensation would occur in walls on the leeward side.

When the outside air temperature is below that inside, stack effect promotes air leakage outwards through the upper portion of the walls and through the ceiling. Under such conditions, condensation would normally be expected to occur in the upper portion of the walls and in the roof space.

In sloped roofs, with an attic space, this moist air can mix with the air in the attic that has entered through the vents provided. In flat roof systems with very little attic space, the moist air leaking through an opening in the ceiling will immediately come in contact with the cold sheathing and condense, without having much chance to mix with the air in the space. In both cases, the rate of removal of moisture by outside air passing through the roof space will be very limited in cold weather, because of the small vapour pressure difference between the frost in the attic and the air flowing through.

In houses with an operating chimney, its exhaust action tends to counteract the outward-acting pressures in the house, so that under most circumstances the air leakage is inward through all walls and downward through the ceiling.[2] The air infiltrating into the house is eventually exhausted with the products of combustion up the chimney.

The chimney action also increases the total air exchange in the house, lowering the indoor humidity and thus the dew point of the indoor air and the amount of moisture in any air leaking outward. It is for these reasons that humidities are generally lower in houses with fuel-fired systems and roof space condensation problems are usually less severe than in electrically heated houses or other houses without operating chimneys.[3]

Exhaust fans can also be used in houses without chimneys and where tightening of the enclosure is not possible, in order to reverse or at least reduce the flow of warm humid inside air into the colder regions of the enclosures.[4]

AIR LEAKAGE AND VENTILATION

Occupants consume oxygen and exhale CO_2 at a rate that increases with activity. If adequate mixing is assumed, a theoretical minimum of about 1-1/2 litres per second per person is required to keep the carbon dioxide levels at a safe concentration value for persons at rest. To allow for increased activity and to handle body odours, a minimum of about 2-1/2 litres per second has been recommended in the past, and currently five litres per second per person is suggested to handle normal contaminants and odours.

The current ASHRAE Standard 62-1981[5] suggests a continuous ventilation rate for residential occupancies of five litres per second per room, and a capability to provide, intermittently, an exhaust rate of 25 litres per second for each bathroom and 50 litres per second for a kitchen. These in combination represent a total exhaust capacity of 75 litres per second; equivalent to about one half air change per hour for an average size house. This same air change rate is also being considered in the proposed revisions for the National Building Code of Canada. If we consider our previous estimates, the tightest house will not provide this rate of ventilation, even when the wind is blowing or when stack effect is at a maximum.

The leakiest house will provide too much ventilation under wind or stack action but not enough under a no-wind, no-stack-effect condition.

Thus, even if we wanted to, making the house leakier provides no guarantee of adequate ventilation at all times.

VENTILATION FOR AIR QUALITY

There are two basic methods of ventilation for air quality control. The most common and most widely accepted is that of dilution where the contaminant source is not fixed (Figure 7). A sufficient amount of fresh air is brought into the space, adequately mixed with the room air to reduce the concentration, and then exhausted from the room in the mixed condition.

If the source of the contaminant can be isolated, a second approach to ventilation can be employed (Figure 8). This is to capture the contaminant and exhaust it to the outside before it can enter the occupied space. This is the approach used with kitchen range hoods and in venting fuel-fired systems, where the products of combustion are captured and exhausted with draft control air up the chimney.

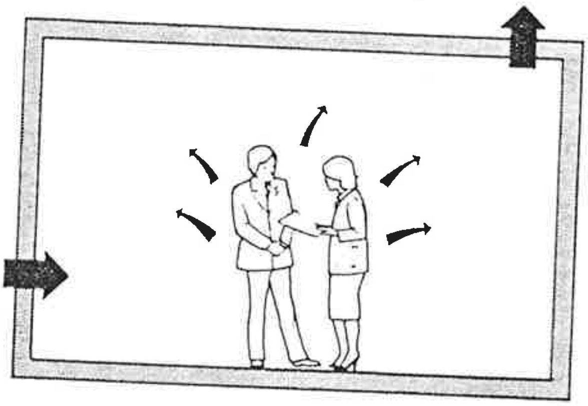


Figure 7

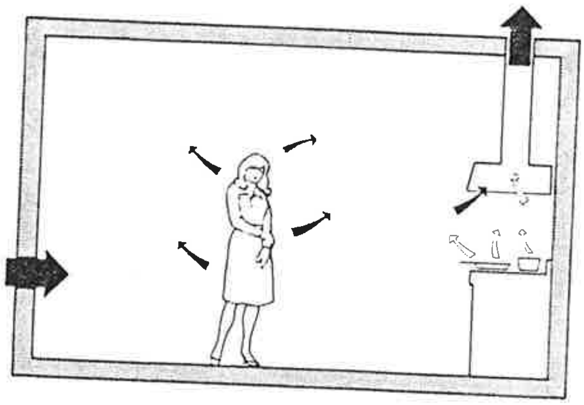


Figure 8

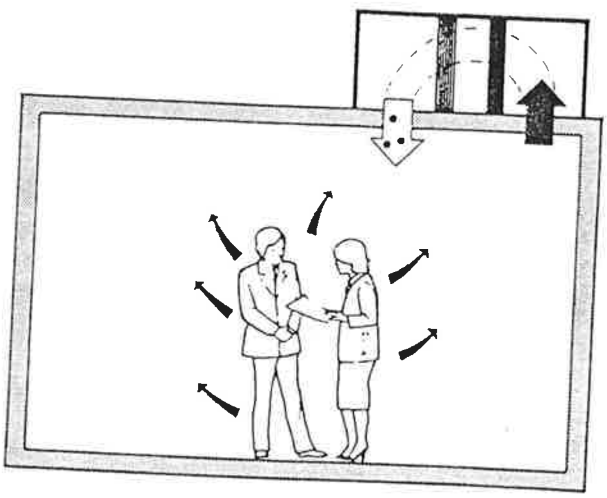


Figure 9

A modification of the dilution approach involves recycling and conditioning the air by passing it through a device (Figure 9) that will remove the offending contaminant or odour, and return the freshened air to the occupied space. A common example of this approach is the recirculating of indoor air through a filter or air conditioner.

VENTILATION FOR HUMIDITY CONTROL

The same principles of ventilation can be applied to humidity control. Introducing colder, drier outside air to the space in winter serves to dilute the water vapour, enabling the drier mixture to pick up moisture produced in the space, and to exhaust the mixture either up the chimney, through an exhaust fan, or by exfiltrating through the house envelope. The rate of moisture removal by this means will depend on the moisture content of the outdoor air, and the rate of flow of the room air to the outside.

If we assume that 75 litres per second is the rate of air exchange (equivalent to the maximum requirement for ventilation for acceptable air quality), the potential rate of removal for given outside conditions can be determined from the psychrometric chart (see page 64 for detailed version of psychrometric chart).

For Toronto, based on the average daily conditions for January, 1.04 kilograms of moisture per hour could be removed at an air flow rate of 75 litres per second. For the rate of moisture supply assumed for a family of four, such an exhaust rate would be capable of controlling the humidity to a level of below 30%.

In the fall, however, the moisture removal capacity of the ventilating air starts at zero, while the rate of supply is highest, due to moisture given off from storage in furnishings and building materials.[6]

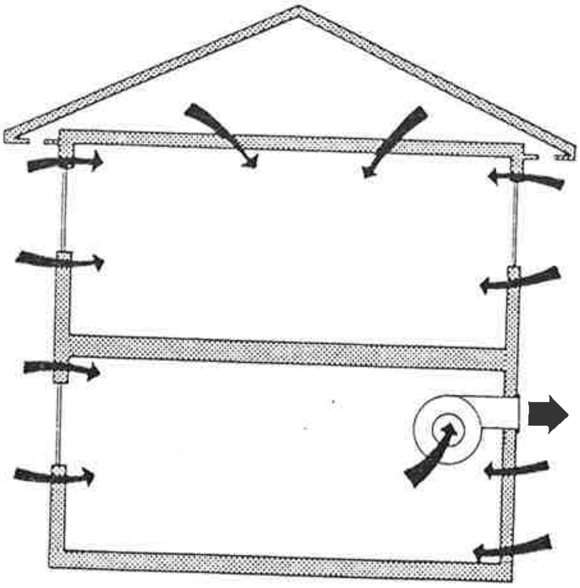
Another approach to the control of humidity would be to utilize the second method of ventilation, that is to capture and exhaust at source, by operating special exhaust fans in high moisture production areas such as the bathroom and the kitchen. It is also the principle employed in the automatic clothes dryer, where room air is brought in to pick up moisture from the wet clothes and exhausted to the outside.

A third means to control indoor humidity levels would be a device to remove moisture from the air by absorption or condensation and return the dried air to the space. A typical example of this is the indoor dehumidifier. Since its capacity is markedly reduced at low humidities, it is not capable of removing much moisture below indoor relative humidities of 40%. It could, however, be effective in helping to control indoor humidity levels in those areas where 40% can be tolerated and where higher humidities are experienced. More important, operation during the summer will reduce the amount of moisture taken up by the wood components and furnishings, and thus reduce the humidity problem in the fall.

VENTILATION SYSTEMS

There are three basic types of ventilation systems; those which operate on the basis of exhaust fans and inlet openings, whereby the interior house pressure is maintained below that of outdoors; a balanced system, with supply and exhaust fans, where the pressure indoors is maintained about the same as that outdoors; and the pressurized system, where outdoor air supply fans maintain the interior house pressure above that outdoors.

Perhaps the simplest system that will provide control of ventilation, and at the same time reduce the problems of condensation within walls and roof spaces, is the exhaust system (Figure 10).



EXHAUST SYSTEM

Figure 10

A single exhaust fan is capable of exhausting the required amount of 75 litres per second from the kitchen and bath, with make-up air being drawn in through leakage paths in the envelope, and in tight houses through special additional openings that allow the fresh air from outside to be drawn into the appropriate rooms. A central centrifugal exhaust fan such as described in CSA Standard C260.2-1976[7] will have a capacity range suitable for such an application.

Ideally, the house envelope should be made as tight as possible and air intake openings with adjustable shutters installed in conjunction with windows, or above perimeter heating devices in each room requiring fresh air. If the house enclosure is tight enough, most of the fresh air will be drawn in through these openings. Such an arrangement would not require any special air distribution system for ventilation.

In the case of a house with a warm air distribution system, a single inlet could be provided from the outside to the return air side of the warm air system, sized or adjusted with a damper or orifice plate to provide the required flow rate, in accordance with the air leakage characteristics of the specific house.

Either of these two systems could incorporate an additional inlet opening or duct for air for any exhaust equipment such as a fuel-fired furnace.

A balanced system (Figure 11) requires an air supply fan in addition to an exhaust fan and, for a house without a warm air recirculating system, some sort of air distribution system to ensure that the air brought in through the supply system is distributed, heated or conditioned and discharged into the rooms where required.

A single supply fan can provide a pressurized system (Figure 12) for certain applications. Pressurization of the house will result in exfiltration of indoor air through all of the existing openings and holes in the house envelope. This could increase the concealed condensation rate but this rate could be reduced by increasing the tightness of the house envelope or by applying insulation to the outside as sheathing.

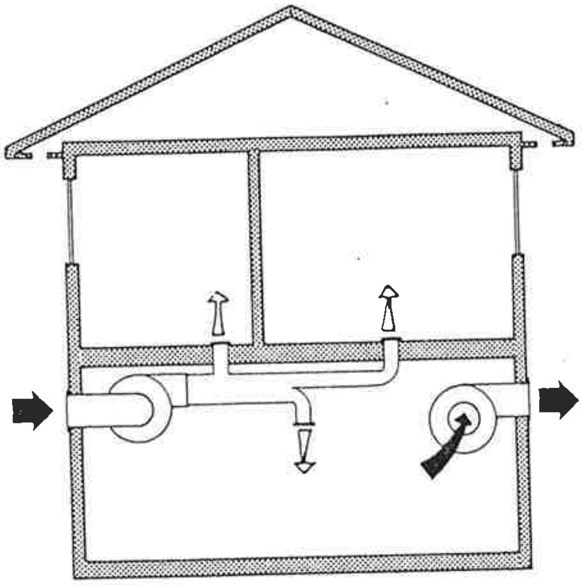


Figure 11

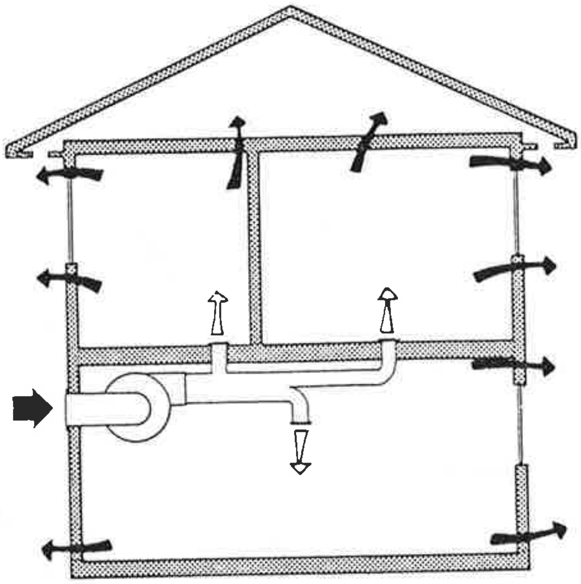


Figure 12

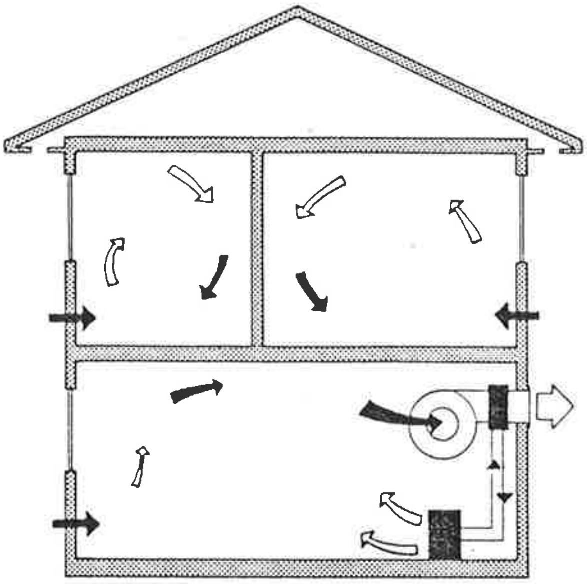
Such a system is appropriate in cases where a contaminant is known to exist in the exterior house walls, such as urea formaldehyde foam insulation. Operating the house under positive pressure will inhibit the flow of any gases or contaminants from the enclosure into the occupied space of the house.

HEAT RECOVERY

In winter, heat is lost only through the air being exhausted. Thus any heat recovery system must first bring all the air to be exhausted from the house through a central point. This is basic to the simple exhaust ventilation system (Figure 13) and a small heat pump could be utilized to extract the heat from this exhaust air and return it either to the space heating system or to the domestic hot water.

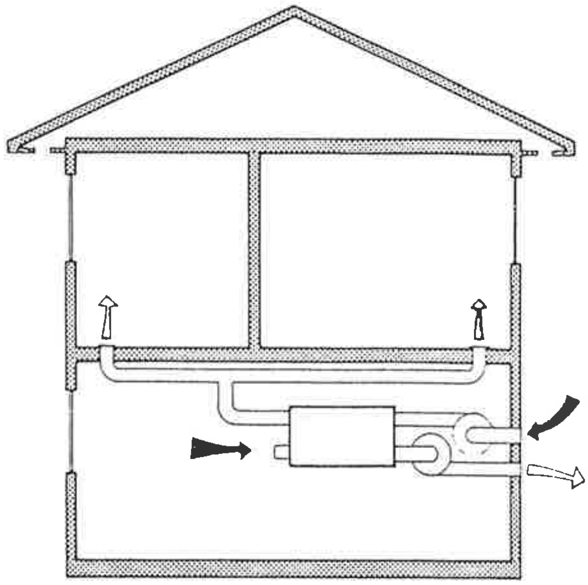
If an air-to-air heat exchanger is to be employed, (Figure 14) not only must the exhaust air be brought to one central point but so must the supply air, in order that heat can be transferred from one to the other.

The amount of heat in the exhaust air can be determined from the psychrometric chart and compared to that in the outdoor air for any particular condition. For a particular flow rate, and assuming average conditions for the heating season, a seasonal energy requirement can be estimated. The amount of heat recovered will, of course, depend on the efficiency of the heat recovery device.



EXHAUST WITH HEAT RECOVERY

Figure 13



AIR TO AIR HEAT EXCHANGER

Figure 14

SUMMARY

A minimum continuous ventilation rate of 35 litres per second is recommended to maintain air quality in houses under normal circumstances, with a capability of 75 litres per second or more for intermittent use for humidity control and contaminant removal. Natural forces cannot be relied upon to provide such rates under all circumstances and a positive, mechanical system is desirable.

Control of ventilation rates and heat recovery can be best achieved through making the house envelope as tight as possible and by providing adjustable inlet and exhaust openings at appropriate locations with exhaust and/or supply fans sized or adjusted for the particular house and system.

If the house envelope cannot be made airtight, an exhaust system has potential advantages for heat recovery and condensation control and is perhaps the simplest system. It will not be suitable for houses where sources of contaminants exist within the house envelope.

Humidity control strategies will depend on the climate of the region and its seasonal and daily cycles. Surface condensation is sensitive to daily variations in climate and operation. Concealed condensation problems relate more to seasonal variations and average monthly or weekly conditions.

Ventilation for humidity control will be least effective in the fall, because the drying capacity of the outside air is at a minimum and the moisture supply rate from the occupants is augmented by moisture coming out of the building materials and furnishings.

Lowering the relative humdity inside the house in summer, using an air conditioner or demhumidifier, will lower the moisture content of the interior materials and thus the moisture supply from storage in fall and winter.

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4. G.T. Tamura, G.H. Kuester and G.O. Handegord, Condensation Problems in Flat Wood-Frame Roofs. CIB/RILEM Symposium on Moisture Problems in Buildings, Rotterdam, September 1974, NRCC 14589.

5. Ventilation for Acceptable Air Quality, ASHRAE Standard 62-1981. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1981.

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QUESTIONS AND ANSWERS

by

Jacques Rousseau, R.L. Quirouette,
M.Z. Rousseau, G.O. Handegord and G.F. Poirier

The text that follows represents a cross section of the most typical questions and answers that were raised during the Workshop periods of the Building Science Insight '83 tour. These questions were answered by Insight authors and arranged in the same order as the papers presented in this proceeding.

QUESTION 1

Is the estimate of 1% of the housing stock with moisture problems considered conservative?

ANSWER - Jacques Rousseau

We feel this figure is probably conservative. The survey conducted for CMHC was not statistically representative, since the population observed was comprised only of those reporting problems. There is a probability that not all problems have been reported: some problems may be considered normal by the homeowner; some problems may not be easily visible, such as those in inaccessible attics or inside wall cavities. There may be some question as to what was defined as a serious problem: a siding which had buckled over less than 40% of a wall area would not be included in these statistics and could constitute a serious problem for some homeowners. However we feel at CMHC that these statistics indicate a problem with our Canadian houses and that we must review our methods and designs to control the problem.

QUESTION 2

Why was the study conducted on houses built since 1973? Was there no problem before? What has changed?

ANSWER - Jacques Rousseau

Although we had problems before 1973, the study was conducted on houses built after 1973 because the occurrence of reported problems was relatively much higher in this group. This was unexpected. We felt that the quality of housing had improved during these years.

In the last ten years, we have changed our houses considerably to comply with the measures for energy conservation. The R value required for walls and attics has been increased. The subsequent reduction in energy losses has led to colder outside wall surfaces, permitting condensation of moist warm air. We have changed our conventional heating systems to flueless systems; this has changed the neutral pressure plane level within the home. Before that change, dry cold air would tend to infiltrate through cracks and other openings; instead, warm moist air now exfiltrates through the same cracks and openings. We have also attempted to seal up the houses. This has reduced the natural ventilation rate in our homes and has limited the dilution of the indoor humidity. These major changes coupled to higher humidity levels increase the potential for moisture problems in our houses.

QUESTION 3

The study indicates that you are unable to determine if siding problems resulted from exfiltration of warm moist air or from rain penetration. Why is this? Can we avoid the problem if we don't know the cause?

ANSWER - Jacques Rousseau

Although we do not know the proportion of the moisture accumulation in cavities which may be due to rain penetration and/or exfiltration of warm moist air, we know the mechanisms by which these problems occur. Exterior walls of the problem houses are subject to exfiltration: the predominant winds are from the west and leeside walls are subject to negative pressure, which results in exfiltration on the easterly oriented walls. However, during rain storms the wind usually comes from the east, which drives the rain into the siding on the eastern face. So one particular wall orientation is susceptible to moisture accumulation by exfiltration and by rain penetration; hence the uncertainty.

The installation of an effective air barrier would go a long way towards resolving these problems. An air barrier would eliminate the leakage of warm moist air through the wall. The same barrier would prevent much rain from penetrating into or through the wall by enhancing the operation of the rain screen system, (see Question 6) which depends on the equalization of pressures.

Alternately, if the house does not have a suitable air barrier, exfiltration of moist air into the wall and ceiling cavities may be reduced by using an exhaust fan ventilation system to lower the indoor pressure. This would induce infiltration at locations which would otherwise have seen exfiltration of moist air.

If exfiltration of air cannot be controlled by either of the above methods, a third approach would be to lower the indoor humidity to a point where the exfiltrating air would be sufficiently dry.

QUESTION 4

What is the moisture production output from whirlpool baths, hot tubs and indoor swimming pools?

ANSWER - R.L. Quirouette

The moisture output from various types of baths, hot tubs and swimming pools is not generally available with the product literature, but it can be computed for each type of installation. The water evaporation rate of various recreational facilities will greatly depend on their use. Such factors as time of use, temperature of air, indoor air circulation, and water temperature must be considered in the calculation of evaporation or water vapour output rate from these devices.

An approximate rate of water evaporation into the air can be obtained by using the formula $W_p = C_3A(P_w - P_a)$*, where W_p is the evaporation rate of water (kg/hr), C_3 is a constant (0.000145), A is the area of exposed water (m^2), P_w is the saturation vapour pressure taken at the surface water temperature (Pa), and P_a is the saturation pressure at room air dew point temperature (Pa). Values of P_w and P_a may be obtained from the ASHRAE handbook (1981 Fundamentals Handbook, p. 6.4) or from the simplified table below. Interpolation may be necessary.

Air or water temp °C	P_w (Pa)	P_a (Pa) at room RH					
	100%	80%	70%	60%	50%	40%	30%
0	611	489	428	367	306	244	183
5	873	698	611	524	436	349	262
10	1228	982	860	737	614	491	368
15	1706	1364	1194	1023	853	682	512
20	2339	1871	1637	1403	1169	936	702
25	3169	2535	2219	1902	1585	1268	951
30	4246	3397	2972	2548	2123	1698	1274
35	5628	4502	3940	3377	2814	2251	1688
40	7384	5907	5169	4430	3692	2954	2215

For example, an indoor swimming pool measuring 4.9 × 9.8 m (16 × 32 ft), having a water surface area of 48 m^2 and indoor conditions of 50% RH at 20°C, (P_a = 1169) with a water temperature of 25°C, (P_w = 3169) will produce [0.000145 × 48 × (3169-1169)] or 13.9 kg/hr of water vapour.

*based on a formula from the 1978 ASHRAE Applications Handbook, p. 4.7, modified to kg/hr instead of kg/s.

QUESTION 5

What should be the indoor humidity level of a house in winter?

ANSWER - R.L. Quirouette

For health reasons it is suggested by the ASHRAE guidelines that 50% RH is the most desirable level of relative humdity in order to maintain airborne infection at a minimum. However, the relative humidity in Canadian housing will vary considerably above and below this mark. During winter the relative humidity may be governed in large part by the type of windows in a residence, either single, double or triple glazing. As most Canadian houses have at least double glazing, the relative humidity should be no more than 30-35% during deep winter (for one or two months). At this level, surface window condensation can be kept to a minimum to avoid damage to sills and to control fungal growth in corners and on surfaces at temperatures below the dew point temperature of the air. With triple glazing the relative humidity levels may be increased slightly, to about 40%. However this will vary with the region, wind effects and outside air temperature. The rest of the year, when outside air temperatures are warmer, relative humidity will generally drift to slightly higher levels, with little condensation occurring on the glass or elsewhere.

QUESTION 6

What is the rain screen principle?

ANSWER - R.L. Quirouette

The rain screen principle is a concept which has been used successfully to minimize rain penetration to the inside of a building enclosure. The rain screen depends on pressure equalization of the outside cladding to minimize the pressure difference that may act on the cladding joints and thus encourage water to enter behind the cladding system. A functional rain screen system depends on three factors. The first is an airtight inner barrier which defines the backside of a cavity and inhibits all air leakage to the inside of the building; second, a compartmentalized cavity (minimum of one per elevation) prevents pressure differences from occurring laterally and/or vertically; and third, a rigid system of materials defines the cavity volume. The rain screen cladding must be sufficiently vented for pressure equalization to occur. Examples of the rain screen which function quite well can be found in commercial institutional construction, that is, precast sandwich concrete wall systems, metal and glass curtain wall systems and some masonry wall systems. A more thorough discussion of the rain screen wall will be found in CBD 40 (see Further Reading).

QUESTION 7

Should inside wall surfaces of concrete be sealed to reduce diffusion of moisture from the concrete as well as from the soil?

ANSWER - R.L. Quirouette

Yes, it would be desirable to seal concrete wall surfaces, as well as basement floor surfaces, to prevent or reduce the amount of moisture entering the building spaces and thus adding extra humidity or moisture load to the indoor air. However, one must consider future changes; if these surfaces are sealed to reduce or control diffusion of moisture to the inside, then if these surfaces are insulated afterwards, there is a danger of positioning the seal as a vapour barrier on the wrong side of an insulated assembly. Some thought must be given to the final assembly in the years to come. Otherwise, the sealant may have to be removed when the concrete wall surfaces are reinsulated, or if a firred sub-floor is to be added to a basement concrete floor.

QUESTION 8

Where does moisture concentrate in a dwelling? Does it stay at the bottom or build up on the top storeys?

ANSWER - R.L. Quirouette

Humid air is slightly lighter than dry air at the same temperature. Therefore, in an undisturbed volume of space, humid air will tend to concentrate at the top of a space and slightly less humid air at the bottom. The difference is small, however - only a percentage point or two. The buoyancy of moist air can be determined from the psychometric chart. It is termed the density of air (the inverse of the specific volume) and the more moist the air is at a given temperature, the lighter it will be.

QUESTION 9

Does an exterior insulating sheathing increase the potential for concealed condensation in wall cavities?

ANSWER - M.Z. Rousseau

It is unlikely. The installation of an insulation material on the outside of a stud cavity wall alters the temperature profile of the cavity itself. In the wintertime, this has the positive effect of reducing the period when the cavity temperature falls below the dew point temperature of the inside air. Therefore, the potential quantity of water vapour that can condense in the cavity or on a sheathing is decreased. Also, because the temperature difference between the inside and the outside of the stud cavity is reduced, it has the effect of reducing potential air convection currents in the cavity.

Some insulating sheathing has a low permeability to water vapour and its presence on the outside of a wood frame wall has raised some concern about the diffusion of moisture through the wall. Moisture diffusing into the wall can be prevented from condensing in the cavity either by reducing its rate of entry or by increasing its rate of escape. Thus, condensation can be controlled by having the inside material less permeable to water vapour diffusion than the outside insulating sheathing. Whatever moisture traverses the cavity by diffusion should get out by the same mechanism.

QUESTION 10

Is venting of an attic space the only way to avoid condensation problems?

ANSWER - M.Z. Rousseau

No. The purpose of ventilation of an attic is to flush out the moisture that enters from the living spaces. In winter, outside air in most geographical locations is close to the saturation point, and therefore ventilation of an attic with saturated air may not be very effective in removing moisture from the attic spaces. The effectiveness of ventilation in removing moisture depends on the quantity of moisture which appears in the attic, the capacity of the outside air to absorb extra moisture, and the flow of air which actually occurs by ventilation. Ventilation openings in attics do not ensure a continuous flow of air; there must also be an air pressure difference. Even then, sufficient air may not be passing through the attic.

Since the source of moisture is likely to be the inside space of the building, it is best to control attic condensation by providing appropriate barriers to moisture movement at the ceiling plane. The ceiling must have an air barrier and a vapour barrier to prevent moisture from entering the attic space.

Attic condensation control is a mixture of efforts; 1) careful air sealing and detailing of the ceiling plane to minimize the entry of moist air into the attic space and 2) provision of ventilation openings to let out some of the moist air. This movement will be more productive in spring, when the outside air has a greater drying potential.

QUESTION 11

Can plywood used as an exterior sheathing act as a vapour retardent on the wrong side?

ANSWER - M.Z. Rousseau

It depends on the construction of the wall. By definition, a vapour barrier or vapour retardant inhibits the diffusion of water vapour to a specific rate. In this context, plywood is not a vapour barrier. However its permeability to water vapour is quite low, near that of an acceptable vapour barrier.

Provided that the materials on the outside of the wall are more permeable to water vapour than the inside materials, i.e. the vapour barrier, the wall assembly meets the requirement for moisture diffusion control. This is a matter of ratio: whatever vapour comes into the cavity at a certain diffusion rate should diffuse out at the same or a higher rate.

If plywood is used on the outside, the vapour barrier must be a less permeable material, such as polyethylene plastic film or aluminum foil.

QUESTION 12

Can plywood sheathing be used as an air/vapour barrier in the double wall approach?

ANSWER - M.Z. Rousseau

If plywood is to be used as an air/vapour barrier, it must be installed in such a way that it can perform two distinct functions. The first is to prevent the leakage of air from inside to outside of the building and vice versa, and the second is to limit the diffusion of water vapour from inside to out.

As an air barrier (not a vapour barrier) the plywood sheathing can be located about anywhere within the wall assembly, as long as the plywood assembly is made continuous at its joints, and continuous with other components performing the same functions; it must also be fastened to the structure so that it can resist peak wind pressure loads. A plywood air barrier can be located between layers of insulation, as in the double wall enclosure. There is a distinct advantage in the double wall approach, as a plane of airtightness may be chosen that is not interrupted by floors or partitions; continuity is therefore easier to achieve in the design and construction of this assembly. Furthermore, an air barrier located between layers of insulation is not exposed to extreme variations in temperature and humidity and thus its joints may have a longer life.

As a vapour barrier (not an air barrier) plywood sheathing has a high resistance to water vapour diffusion but not high enough to meet the requirements of Type 1 vapour barrier as defined by CGSB. In order for plywood to qualify as a Type 1 vapour barrier, it would need to be coated with a special paint or an extra film such as foil or plastic to enhance its vapour resistance. Assuming that a plywood coated with a special paint is intended to be used as a vapour barrier, it should be located on the warm side of the insulated assembly. However, a vapour barrier may be located within an insulated assembly as far from the inside wall as the point where one-third of the thermal resistance of the wall has been reached, and still not have any significant amount of moisture condensing on its surface. The continuity of plywood as a vapour barrier is desirable, but it is not as critical as with an air barrier assembly.

QUESTION 13

What is the purpose of perforating plywood panels used as exterior wall sheathing?

ANSWER - M.Z. Rousseau

The usual goal is to control concealed condensation problems. This may not be the best way to do it.

With regard to moisture diffusion across such a wall assembly, holes in an outside sheathing increase the rate of moisture diffusion to the outside. As mentioned earlier, diffusion of moisture can be controlled either by reducing considerably the entry of moisture into the wall or by increasing its escape to the outside. Making holes in the outside material is the latter approach.

With regard to air leakage, making holes in the exterior sheathing is a viable approach only if the inside skin of the wall is airtight. If there is no airtight assembly across the enclosure, the holes in the plywood exterior sheathing will induce a greater flow of moist inside air through the wall and a greater potential for condensation problems.

Even when holes are not deliberately made, most designers and builders leave gaps between the panels. If there is no provision for ensuring airtightness elsewhere in the walls and their interface, concealed condensation is likely to occur, whatever material is used for the exterior sheathing.

QUESTION 14

How should you specify ventilation rates?

ANSWER - G.O. Handegord

Ventilation rates should be specified in terms of volumetric flow per unit of time, that is litres per second or cubic feet per minute, for the occupancy in question. For human occupancy, under normal circumstances the volumetric flow rate would be five litres per second per person.

QUESTION 15

How do you remedy the problem of excessive airtightness?

ANSWER - G.O. Handegord

You don't; airtightness of the enclosure enables you to control the indoor air quality.

QUESTION 16

How do you make an electrically heated house comfortable, from a humidity point of view?

ANSWER - G.O. Handegord

You may use a dehumidifier if the humidity is too high, or an exhaust fan linked to a humidity control.

QUESTION 17

What do you do to prevent discomfort, from air drawn in at cracks, in an exhaust-only system?

ANSWER - G.O. Handegord

To prevent discomfort from cold drafts, you should maintain air circulation in the room by operation of a central fan in a warm air system or augment circulation in electric baseboard systems. If the house is sized to introduce 35 to 70 litres per second of air, infiltration of 5 to 10 litres per second per room should not be noticed.

QUESTION 18

Would you recommend manipulating the neutral pressure plane of an airtight structure, to avoid upper wall and attic condensation?

ANSWER - G.O. Handegord

It is preferred that the house be operated in a depressurization mode, since it is possible to recover heat from exhaust air.

QUESTION 19

In what ways can a forced ventilation system be controlled? (Humidistat?)

ANSWER - G.O. Handegord

A forced ventilation system can operate continuously at approximately 35 litres per second and be on a manual automatic control for non-occupancy or increased ventilation rate.

QUESTION 20

How does CGSB measure the airtightness of a house?

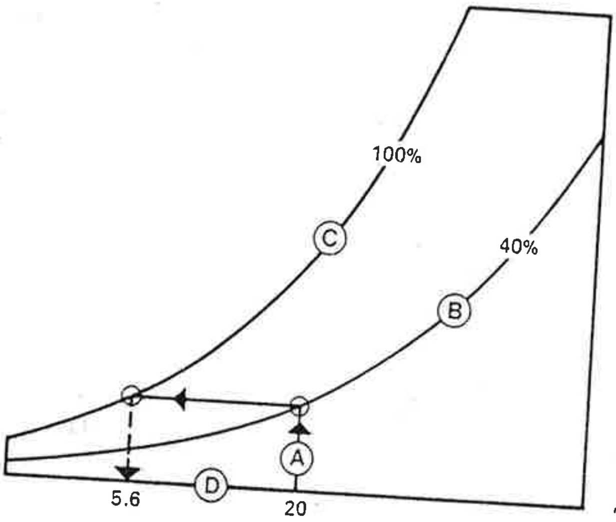
ANSWER - G.O. Handegord

The CGSB standard uses depressurization (exhaust) for measuring volumetric flow per unit time at different inside-to-outside pressure differences. These differences will vary from 10 pascals to approximately 50 pascals.

QUESTION 21

How do you determine the dew point temperature of the inside air using the psychrometric chart?

ANSWER - G.F. Poirier



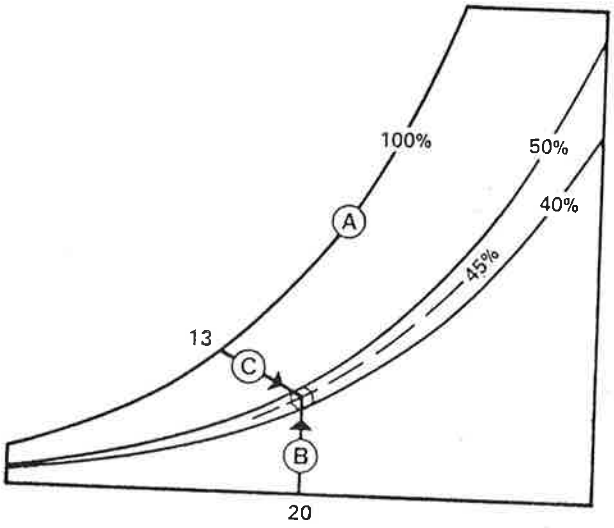
To find the dew point temperature of the inside air, two properties of the air must first be measured. For example, let us assume that the dry bulb temperature is measured at 20°C and the relative humidity is 40%. On the psychrometric chart, find the point of intersection of the 20°C dry bulb temperature coordinate (A) and the 40% relative humidity curve (B). From the point of intersection (state point) move horizontally to the left to intersect the saturation (or 100% RH) curve (C). This point of intersection corresponds to 5.6°C on the dry bulb temperature scale (D). Therefore, 5.6°C is the dew point temperature of the air at the above conditions. Any surface exposed to these conditions having a surface temperature below 5.6°C will condense moisture from the air.

QUESTION 22

How do you determine the relative humidity of the inside air with a psychrometer and the psychrometric chart?

ANSWER - G.F. Poirier

The psychrometer is a self-contained instrument and may be manual (a sling psychrometer) or motorized. Both types use the same principle of operation; the explanation that follows assumes the use of a motorized type. It consists of a miniature fan and two ordinary room temperature thermometers, one with a thin sock covering the bulb. To take a reading, the thin sock is soaked with distilled water and the fan is operated for a few minutes to pass ambient air by the thermometer bulbs. If the inside air is not saturated, water from the wet sock will evaporate, lowering the temperature until the wet bulb comes to equilibrium with the sampling air. The temperature obtained by the wet bulb thermometer is called the wet bulb temperature. The other thermometer reads the dry bulb temperature (air temperature).



Assume that readings of 20°C dry bulb temperature and 13°C wet bulb temperature are obtained. On the psychrometric chart the wet bulb temperature lines run diagonally; the wet bulb temperature scale is along the saturation curve (A). To determine the relative humidity of the air, find the point of intersection of the 20°C dry bulb temperature line (B) and the 13°C wet bulb temperature line (C). The intersection indicates a state point between the 40% and 50% relative humidity curves. From the position of the state point the relative humidity of the inside air can be estimated at 45%.

QUESTION 23

What quantity of moisture can be removed by ventilation?

ANSWER – G.F. Poirier

Moisture can be removed by ventilation only if the outdoor air introduced in the space is drier than the inside air. The rate of moisture removal will depend on the difference of moisture content between the inside and the outside air, and on the quantity of room air exhausted to the outside. Ventilation to remove moisture is most efficient during the coldest months of winter, because the outside air is generally at its lowest moisture content.

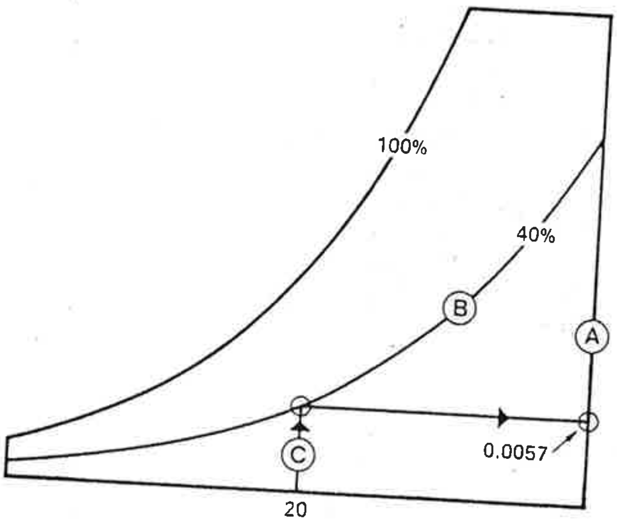
The rate of moisture removal by ventilation can be calculated by the following equation, which is an algebraic rearrangement of an equation from the ASHRAE Handbook (1978, Applications Volume, p. 4.7, eq. 3) for calculating the ventilation required to evacuate evaporated water from a swimming pool:

$$W_r = Q \times C \times (W_i - W_o) \times 3.6$$

where:

W_r = rate of moisture removal (kg/hr)
Q = ventilation rate (L/s)
C = standard air density (1.2041 kg/m^3)
W_i = moisture content of inside air (kg/kg dry air)
W_o = moisture content of outside air (kg/kg dry air)
3.6 = constant $\frac{sec \times m^3}{hr \times L}$.

To apply the equation, let us assume a house with a ventilation system that provides a constant ventilation rate of 35 L/s. The conditions inside the house are 20°C dry bulb temperature and 40% relative humidity. The outdoor conditions are -5°C dry bulb temperature and 80% relative humidity. At this point the only information missing is the moisture content of the inside and outside air. This information can be obtained from the psychrometric chart using the above conditions.



On the psychrometric chart the moisture content is indicated by the vertical axis on the right hand side (A) in kilograms of water per kilogram of dry air. To obtain the moisture content of the inside air, find the point of intersection of the 40% relative humidity curve (B) and the 20°C dry bulb temperature coordinate (C). From the point of intersection, move horizontally to the right to intersect the moisture content scale. The moisture content of the inside air should read 0.0057 kg of moisture/kg dry air. By repeating the procedure for the outside conditions, one should obtain a moisture content for the outside air of 0.002 kg of moisture/kg dry air.

By introducing the above information into the equation, we are able to calculate the rate of moisture removal under the assumed conditions:

$$W_r = Q \times C \times (W_i - W_o) \times 3.6$$
$$= 35 \times 1.2041 \times (0.0057 - 0.002) \times 3.6$$
$$= 0.156 \text{ kg/hr.}$$

The rate of moisture removal is 0.156 kilograms of water per hour or (0.156 × 24 hrs) 3.74 kilograms per day.

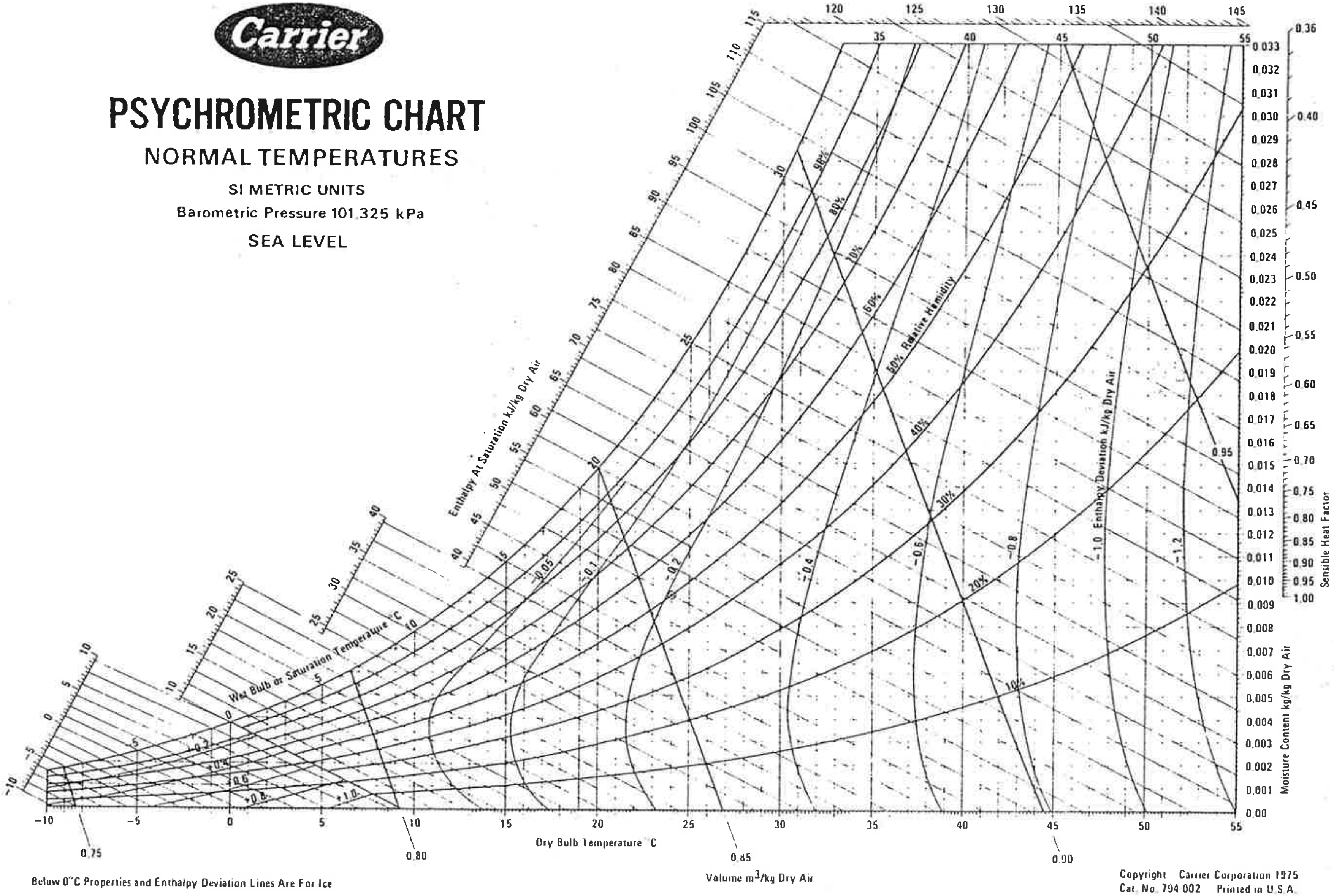
PSYCHROMETRIC CHART

NORMAL TEMPERATURES

SI METRIC UNITS

Barometric Pressure 101.325 kPa

SEA LEVEL



BUILDING SCIENCE INSIGHT '83
HUMIDITY, CONDENSATION AND VENTILATION IN HOUSES

FURTHER READING

For those wishing to pursue the subject of this Insight further, the following references are available. They may be obtained from the Publications Section, Division of Building Research, National Research Council Canada, Ottawa, Canada, K1A 0R6.

Humidity in Canadian Buildings	CBD 1	- N/C
Condensation on Inside Window Surfaces	CBD 4	- N/C
Humidified Buildings	CBD 42	- N/C
Vapour Diffusion and Condensation	CBD 57	- N/C
Weather and Buildings	CBD 14	- N/C
Water and Building Materials	CBD 30	- N/C
Requirements for Exterior Walls	CBD 48	- N/C
Ventilation and Air Quality	CBD 110	- N/C
Wetting and Drying of Porous Materials	CBD 130	- N/C
Moisture and Thermal Considerations in Basement Walls	CBD 161	- N/C
Water Vapour as a Tracer Gas for Measuring Air Change Rates in Houses	NRCC 21002	- $1.50
The Need for Improved Airtightness in Buildings	BRN 151	- N/C
The Effect of Mechanical Ventilation on the Air Leakage Characteristic of a Two-Storey Detached House	BRN 204	- N/C
Air Leakage, Ventilation and Moisture Control in Buildings	NRCC 20752	- $1.25