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HUMIDITY AND BUILDINGS

BY

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Increasing attention is now being given to the provision of modified and controlled relative humidity in buildings for certain occupancies. New considerations are thus introduced in the selection of the humidities to be carried, which must be realistically appraised in terms of need or desirability as well as of the problems which may arise in the provision of them. The severe winter climate in Canada makes it necessary to give special attention to the problems associated with increased indoor humidities during cold weather, not only in the provisions which must be made so that humidities can be maintained, but also in the design of the building enclosure in order to avoid accelerated degradation and increased maintenance. The paper discusses these various considerations and indicates in general terms what must be done when increased indoor relative humidities must be carried in winter.

On s'occupe de plus en plus à l'heure actuelle de maintenir dans les maisons des humidités relatives modifiées et contrôlées pour certains usages. De nouvelles considérations sont ainsi introduites dans le choix des humidités à maintenir. Ces humidités doivent être evaluées de façon réaliste en fonction des besoins ou des conditions désirables ainsi qu'en fonction des problèmes qui peuvent se faire jour à cause d'elles. Le sévère climat d'hiver au Canada fait qu'il est nécessaire de porter une attention spéciale aux problèmes associés avec les humidités accrues à l'intérieur durant les périodes froides non seulement en ce qui concerne les mesures à prendre pour que les humidités puissent être maintenues mais aussi en ce qui concerne la conception des bâtiments eux-mêmes afin d'éviter la dégradation accélérée et l'entretien accru. L'étude passe en revue ces diverses considérations et indique en termes généraux ce qui doit être fait lorsque des humidités relatives accrues sont requises à l'intérieur en hiver.

HUMIDITY AND BUILDINGS

by N. B. HUTCHEON *

This paper was presented at the Symposium on Controlled Humidity in Buildings, at the Construction Industry Exhibition in Montreal, Que., November 20, 1963

A building volume of 10,000 cubic feet, about that of the average house, contains about 750 pounds of air. Associated with this amount of air there will be from 2 to 12 pounds of water vapour, amounting on the average to about 1 per cent by weight of air. This water vapour content of the air, though relatively small, can be an important part of the environment provided for people, goods and processes.

Relative Humidity

Most common materials have an affinity for water, so that their moisture content is influenced by the moisture in the air surrounding them. This important effect, along with several others, is primarily related not to the absolute moisture content of the air but to its relative saturation or relative humidity.

There is a definite limit to the amount of water vapour that can be held in the air at any given temperature. As the temperature increases, the capacity of the air to hold water vapour increases markedly. Several important considerations follow immediately from this. Air at a low temperature outdoors in winter when fully saturated, that is at 100 per cent relative humidity, contains very much less water vapour than can be held at room temperature. For example, the saturation moisture content at —20°F is 0.026 per cent while that at 73° F is 1.76 per cent or 68 times as much, the *relative humidity* being 100 per cent in both cases. When such outdoor air is brought indoors and warmed to room temperature without the addition of water vapour, the amount of water vapour which it contains is only 1½ per cent of that which it requires for saturation at its new temperature. That is, it will be at 1½ per cent relative humidity. This explains why many buildings, ventilated with outdoor air in winter, but without intentional humidification may have relative humidities of only 5 or 10 per cent.

There is always some gain of moisture within every normal building. This may come from people, from washing, cooking, and drying of clothes in the case of dwellings, and from a variety of wet processes carried on in other buildings. It does not follow that because there is no intentional humidification the indoor relative humidity will always be low; some buildings have ample moisture supplied from internal activities and many require increased ventilation to reduce the relative humidity even in winter.

Condensation in Buildings

One of the problems that arise in winter with too high a relative humidity indoors is that of condensation. This can be demonstrated by consideration of the reverse case to that involved in ventilating with air drawn from outdoors in winter. Air which is at 50 per cent relative humidity at 73°F has 0.88 per cent moisture content by weight and is 50 per cent saturated. But this moisture

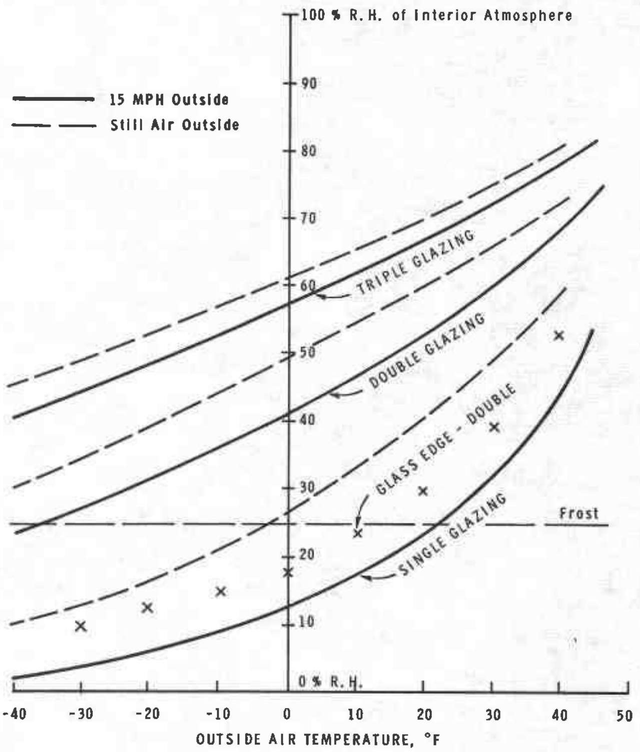

Figure 1 Relative humidity at 70°F at which condensation on inside surface glazing occurs for various outside air temperatures.

content is sufficient to saturate air at 54°F which, because of its lower temperature, requires less moisture for saturation. Cooling of air at 73°F, 50 per cent RH to 54°F will therefore produce saturation, that is, the relative humidity will be 100 per cent. When cooled below this point condensation must occur, since the air can no longer hold its original moisture content. The excess moisture will be rejected as dew on the cooling surface, or as frost if the surface is below the freezing point. The temperature at which an air-vapour mixture will become saturated upon cooling is called the dew-point temperature, and this is another way to describe its moisture condition. Naturally, as indoor relative humidities at a given temperature are decreased, the dew-point temperature also decreases, since the air must then be cooled to some lower temperature to produce saturation. It is apparent then that under winter conditions when exterior walls and windows are cooled below room temperature the indoor relative humidities may have to be limited in order to avoid condensation on

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cool surfaces. On the other hand, when it is known in advance of construction that a particular relative humidity must be maintained, the design of the building can be adjusted appropriately.

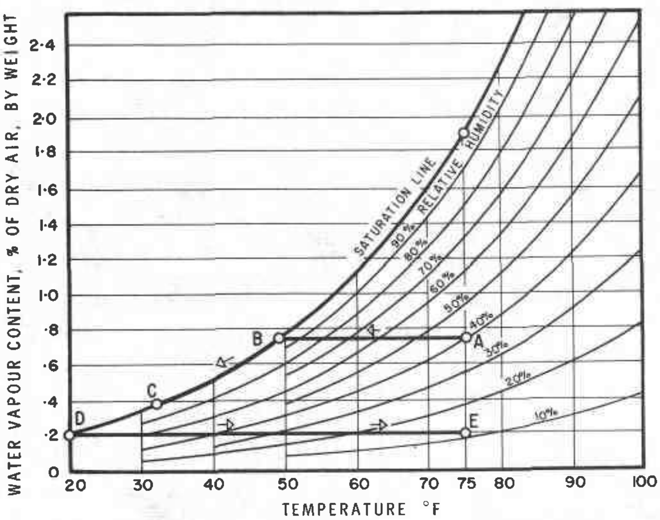


Figure 2 Simplified psychrometric chart showing properties and processes of air and water vapour mixtures.

Cooling and Dehumidification in Summer

The situation in summer is potentially one requiring both cooling and dehumidification. In Ottawa, for example, the combination of high temperature and high relative humidity outdooors may occasionally reach a limiting value represented by an outdoor dew point of almost 80°F. This corresponds to a moisture content of 2.2 per cent and requires during conditioning to 75°F and 50 per cent RH, the removal of water to the extent of 1.3 per cent of the weight of ventilating air being processed. Added moisture sources within the space can add further to this dehumidification load.

The Control of Relative Humidity

The relative humidity within a building may be allowed to vary naturally, without the aid of intentional humidification or dehumidification. It can then vary from low values in heated buildings in winter to high values in summer, as determined largely by the moisture content of the ventilating air. The presence of significant moisture sources within the building will always result in increased relative humidities, which can in part be offset at times by increased ventilation. With high moisture sources in winter or summer, condensation can take place within buildings and will itself provide a limit on conditions if allowed to occur.

Intentional humidification and dehumidification can be employed separately as required or as integral functions of a complete air-conditioning system. In either case decisions must be made as to the levels and the precision of control of relative humidity to be provided, and for guidance in this it is necessary to consider the influence of relative humidity on people, materials and processes, as well as upon the enclosing construction.

Relative Humidity and Materials

All porous materials as well as most natural organic materials have large internal surfaces which exert forces of attraction on water molecules. Consequently these materials have natural moisture contents which vary with the relative humidity of the atmosphere to which they are exposed, provided that there is the time and the opportunity for any necessary adjustment in moisture content to take place.

Many natural organic materials become hard or brittle at low moisture contents so that control of moisture content at moderate or high levels by the maintenance of high relative humidities may be necessary in processing them, as in the case of cigar- and cigarette-making. In other cases it may be necessary to reduce relative humidities to inhibit the growth of fungi or bacteria or to prevent chemical changes such as the corrosion of metals.

Significant dimensional changes take place in many materials with change in moisture content. The best known are those which take place in wood, of the order of 0.1, 2, and 4 per cent in the longitudinal, radial, and tangential directions respectively on a change from air-dry at 12 to 15 per cent moisture content corresponding to about 65 per cent RH, to oven-dry conditions. Most wood-fibre products, including papers, will exhibit moisture expansion consistent with the basic wood properties. Almost all plant and animal fibres experience appreciable moisture changes with changing relative humidity and undergo substantial dimensional changes of the same order as those in wood. Less generally recognized are the dimensional changes that can occur in masonry materials as a result of changes in moisture content.

The cycling of relative humidity, leading to changes in moisture content and to corresponding dimensional changes can, when repeated many times, produce degrading physical effects in some materials. Combinations of materials having different moisture response characteristics, when put together at one relative humidity and then changed to another, may warp or in extreme cases may be ruptured as a consequence of the dimensional changes which are produced.

Thus three distinct requirements for relative humidity control within buildings may arise because of humidity effects on materials:

1. Low relative humidities may be required in order to slow down or prevent degrading chemical or biological changes. Close control of the level of humidity may or may not be necessary.
2. High relative humidities may be required to promote moderate to high moisture contents which are desirable in handling or processing. Close control of the level of humidity may be necessary.
3. Maintenance of a constant relative humidity may be desired in order to minimize degrading or otherwise undesirable dimensional changes during processing, use, or storage. Closeness of control required will depend upon the response characteristics of the materials involved and the degree of dimensional control desired.

It may be noted that a conflict in requirements may exist. Low humidities may be desired for preservation, while some compromise may be necessary if the materials must also be handled. This is the case in libraries, where it may be highly desirable also to maintain constant relative humidity in order to avoid degrading dimensional changes in rare books and papers.

Relative Humidity and People

It has long been accepted that thermal sensations of comfort are affected by relative humidity and that for the same comfort a higher temperature is required to offset a decreased relative humidity. The research work on which these conclusions were based is under review and it is now evident that the earlier conclusions drawn from it apply mainly to the thermal sensations experienced over limited periods of time after leaving one room for another at a different relative humidity. This effect will be well known to those who have occasion to move from one controlled temperature room to another at the same temperature but different humidity. It is due in large part to the thermal effects involved in the rapid readjustment of the moisture content of clothing to the changed relative humidity. For conditions of prolonged exposure to the same relative humidity at temperatures within the comfort zone, most people engaged only in light work will detect little change in thermal sensations of comfort over a wide range of relative humidities.

It has been argued that, with increased relative humidity, lower temperatures may be maintained with the same comfort but with consequent savings in heating costs. This argument may be contested on two counts. The comfort conditions are not likely to be equivalent for prolonged occupancy, and the energy cost to evaporate the added water required for humidification will often more than offset the saving to be gained by reducing temperature.

Arguments favouring the reduction of relative humidities to moderate levels indoors under summer conditions would appear to be somewhat more valid. Although the effects of relative humidity upon the comfort, or more properly the degree of discomfort, of people engaged in moderate to high levels of physical activity have not yet been carefully re-examined, there is little reason to doubt that relative humidity has a marked influence under conditions of sweating. It seems reasonable to assume that reduced relative humidity may provide comfort over a wider range of physical activity for the same temperature in occupancies of mixed activities, as in the case of people seated in a ballroom while others are dancing.

There may well be valid arguments against low humidities, on grounds other than thermal comfort since they undoubtedly lead to increased evaporation from membranes of the nose and throat, and to dry skin and hair. There is little conclusive evidence, however, of serious hazards to health despite the fact that millions of Canadians have lived and worked under low humidity conditions for winter after winter.

It seems logical to assume that, in general, extremes of humidity are undesirable and that relative humidities should be kept within a broad range of 30 to 70 per cent. There is, however, no firm basis for establishing such limits so far as the health and comfort of most people are concerned.

Electrostatic Effects and Humidity

It is well known that electrostatic charges capable of producing large and often unpleasant sparks when discharged can be generated by walking or sliding on a carpet in winter. This comes about by a separation of electrical charges when materials of high electrical resistance are brought intimately into contact by sliding one over the other. Difficulties may be encountered in the handling of paper sheets, fibres and fabrics which, when charged, may be attracted or repelled by one another or by other bodies depending on the nature of the charges. Control of dust or lint may also be a problem when it is attracted and clings to oppositely charged objects. Other difficulties may be introduced when explosive gas mixtures are present since these may be ignited by accidental electrostatic spark discharges.

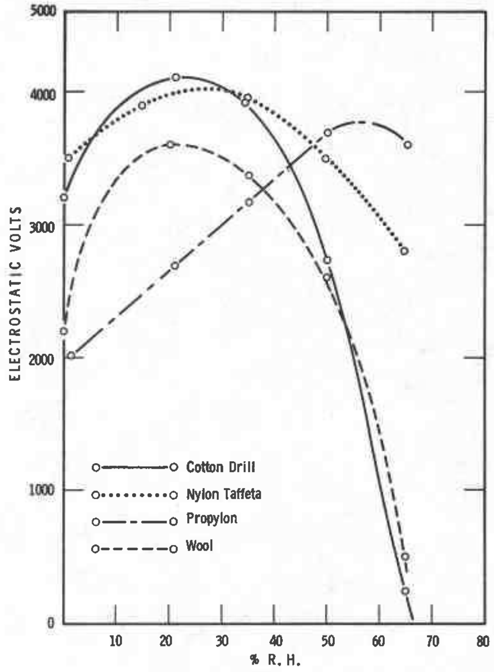


Figure 3 Electrostatic charging on fabrics at different relative humidities.

The water layer which is held on most surfaces becomes sufficiently thick as the relative humidity is increased so that it prevents the accumulation of such charges. An increase of relative humidity to 50 per cent or more will usually be necessary to reduce or eliminate undesirable electrostatic effects with many materials; wool and some synthetic materials may require still higher humidities.

Electrostatic charging may, however, be a maximum at a relative humidity of from 25 to 35 per cent under some conditions and even higher in a few special cases so that increasing the relative humidity from a low value may actually increase the difficulty unless it is carried sufficiently beyond the value at which the effect is a maximum. Electrostatic effects are sometimes so serious, as in the case of hospital operating rooms where explosive mixtures of anaesthetics are used, that they may determine the humidity levels to be carried. The unpleasant shocks experienced by guests in hotels may even be cause for serious consideration of increased humidities. The reverse situation may be encountered in electrical or electronics work where a requirement for the highest possible electrical resistivity may call for the maintenance of low humidity.

Relative Humidity and Auditoria

A very interesting humidity effect is involved in air absorption of sound waves. It is found that air absorption is quite substantial for the higher frequencies and is a maximum in the relative humidity range of 15 to 20 per cent with absorption increasing as the frequency increases.

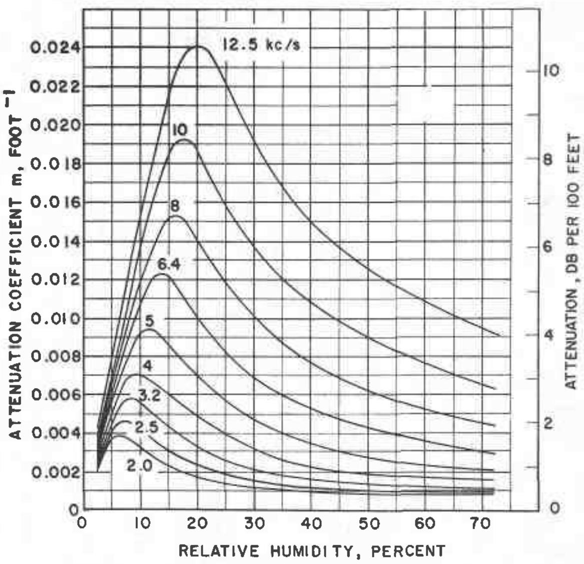


Figure 4 Effect of relative humidity on air absorption of sound at different frequencies. (Reproduced with permission from "Absorption of Sound in Air in the Audio-Frequency Range", Journal, Acoustical Society of America, Vol. 35, January 1963.

The effect will be of little importance for speech but may merit consideration in the case of large halls or auditoria which are required to have very good acoustic properties for musical performances. An increase in relative humidity to 40 per cent provides a marked reduction in absorption, and at 50 per cent the effect may for practical purposes be considered unimportant.

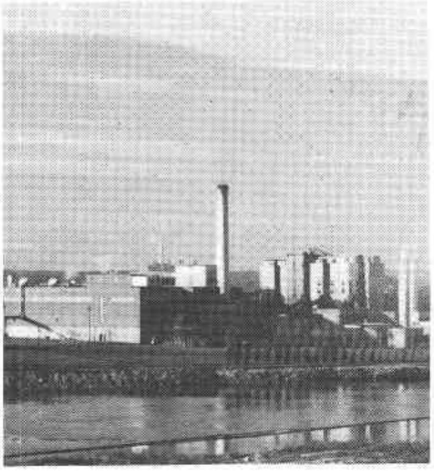
Practical Considerations

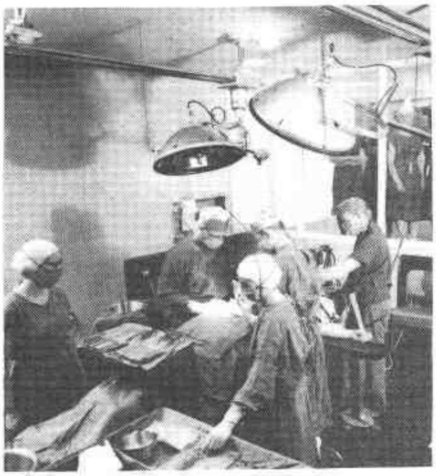
It might be concluded from the discussion thus far that a constant relative humidity of 50 per cent maintained the year 'round would be ideal for some conditions of occupancy and a good compromise in others. Indeed, this is a commonly adopted value for many laboratories and workrooms in which constancy of relative humidity is a major requirement. But there is a great difference in the air-conditioning equipment required, and therefore in the cost, to maintain relative humidity reasonably constant, in comparison with the more usual comfort conditioning in which temperature is controlled but relative humidity varies over a range depending on the load and system characteristics. Reasonably constant relative humidity can be provided, but only at a price. The more closely the relative humidity must be held, the greater the over-all cost will be.

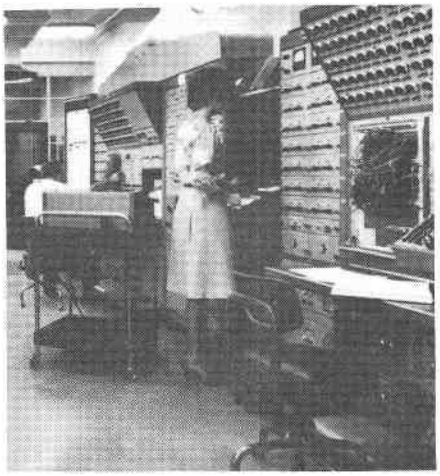
It must not be assumed that close humidity control is dependent only upon the equipment provided. The characteristics of the system and of the whole building must be taken into account. For example, it is useless to provide sensitive humidity control capability if temperature is not also closely controlled and held constant throughout the work area. Since a 1°F change in temperature at 73° causes an RH change of 3 per cent of the RH involved, the air temperature variations throughout the area to be controlled must also be held within appropriate tolerances. In addition, variable radiation effects from cold walls, hot sources, and solar effects which cause the temperatures of irradiated objects to differ appreciably from air temperature may have to be eliminated. Finally, the air infiltration as well as the air distribution must be carefully controlled, since this may cause variations in the water vapour distribution throughout the space, thus nullifying the effects of close temperature and humidity control at the humidistat locations. The importance of these matters increases as the control precision increases, and in the extreme they may dictate many features of the enclosure, layout, and use of the enclosed space.

The level of the humidity to be maintained also has important practical implications. Dehumidification in summer to provide control at 50 per cent RH can be obtained with chilled water. If the relative humidity is to be held much below this value, however, chilled water systems cannot be used because of freezing, and other types of dehumidification equipment must be considered. On the other hand, problems may be encountered in the design and operation of the building when the relative humidities to be carried during the coldest weather are much above 20 per cent. For these reasons it will often be practical to adopt a compromise and to maintain 50 per cent RH in summer and some lower relative humidity in winter, thus easing both the dehumidification and the building problems.

A steady increase can be expected in the number of buildings that must be constructed to provide a constant indoor humidity of 50 per cent or higher both winter and summer. These will probably include hospital operating and clinical rooms, research laboratories, and libraries, museums, and art galleries housing valuable collections. In some of these cases a reduction in the winter level of relative humidity may be accepted to ease the building design problem.







(1) Paper Mill (2) Operating Room (3) Computer Equipment

Figure 5 These activities require buildings capable of carrying increased relative humidity in winter. (1) Photo - DBR/NRC; (2) Photo - Ottawa Civic Hospital; (3) Photo - Division of Mechanical Engineering, NRC.

But it is quite apparent that there is a growing demand for increased relative humidities in winter in all kinds of buildings designed primarily for human occupancy. This stems partly from the more widespread acceptance of air-conditioning and probably also from the improved humidity conditions which are now possible, and widely maintained, in Canadian dwellings.

It is of the greatest significance that buildings in greatly increasing numbers will be required to carry higher relative humidities in winter. This requires the most careful consideration of designers and builders alike, since, without an enlightened design approach, buildings will either experience serious degrading effects with increased maintenance or reduced life or will be changed to operate at humidities below those originally desired. In the latter event, the extra investment made in equipment and building to provide humidity will be wasted. The principles to be followed in design are already well known; there remains only the problem of putting them into practice.

The Division of Building Research of the National Research Council has for a long time been aware of the potential difficulties in increasing the humidities in commercial and industrial buildings. Many of the issues of Canadian Building Digests which are designed for wide distribution throughout the country have been devoted to topics pertinent to the design of buildings for increased winter humidities (1 to 12). Future issues will deal further with this most important subject. Some of the principles to be followed will now be reviewed briefly.

Building Design for Humidity

It is first of all essential to arrange that all interior surfaces be kept at temperatures above the dew-point temperature of the desired indoor conditions under the lowest sustained winter temperatures to be encountered. Windows

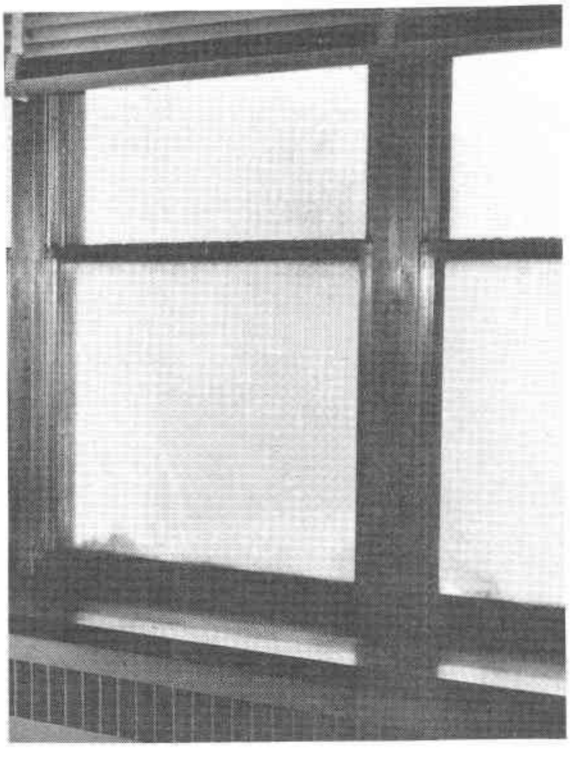


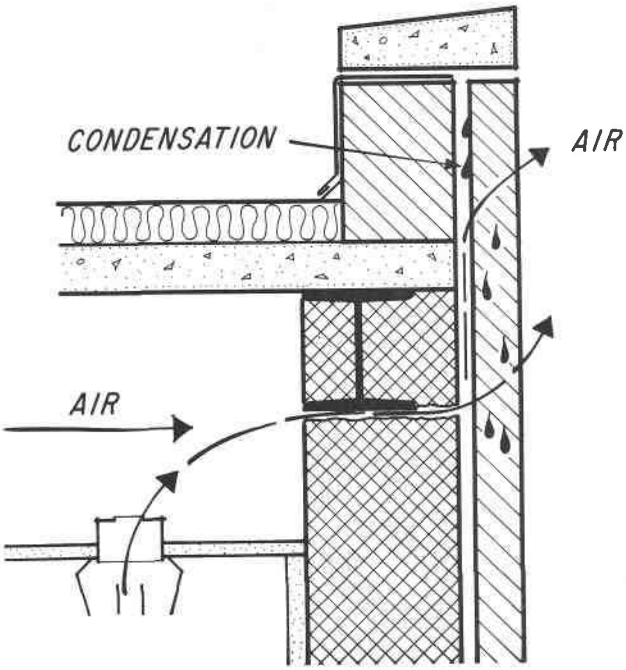
Figure 6 Indoor relative humidities in winter in excess of the limit set by cold window surfaces lead to condensation.

will pose the most obvious problem in this regard since they are usually poorer thermally than walls. Current practices, even with double windows, will limit humidities to 20 per cent or less in most parts of Canada, but double windows can be arranged, as they have in houses for many years, to carry humidities of 30 to 35 per cent, while triple windows become necessary in order to carry 50 per cent without difficulty. For still higher humidities, it will become necessary to eliminate windows or to use double wall designs. Maintenance of surface temperatures above the dew point is a minimum requirement to minimize problems with the building. An even higher level of temperature may be necessary to limit radiation effects when close humidity and temperature control are required. When great refinement in control is required it will be necessary to avoid outside walls completely and to provide close control in interior enclosures only.

There are usually many other parts of the enclosing construction in addition to windows which are weak points thermally in today's designs. Paths of high thermal conductivity leading to reduced inside surface temperatures occur where columns, spandrel beams, and the edges of slabs and cross-walls intrude into or through the exterior wall. Attempts to insulate these members on the inside will usually not be successful, at least for extreme cases; the proper place for insulation is on the outside of them.

The second set of principles relates to control of water vapour flow into the wall in order to avoid condensation and serious degrading effects within the enclosure. Make the entry of water vapour into the wall from the inside as difficult as possible and its escape to the outside, once it has entered, as easy as possible. Water vapour may move into a wall by diffusion, and must be stopped on the warm side by the judicious use of vapour barriers or other components providing resistance to vapour flow. But water vapour, it is now known, can be fed into an exterior wall, in very substantial quantities, by air leakage. It is therefore necessary to ensure reasonable air-tightness, preferably on the warm side of the wall, and particularly at the upper portions of a building since, due to chimney action in winter, air leaks in at lower floors and outward at upper floors of any heated building.

Careful attention should be paid to all possible dimensional changes arising from shrinkage, creep, temperature and moisture effects throughout the enclosure and the portions of the building frame associated with it. Cracks on the warm side of the wall which will allow air leakage should be anticipated and adequate sealing provided at the outset at strategic points. Particular care should be taken at all critical sections such as the junction of wall and roof, and below window sills to ensure that adequate protection against vapour and air flow is provided.



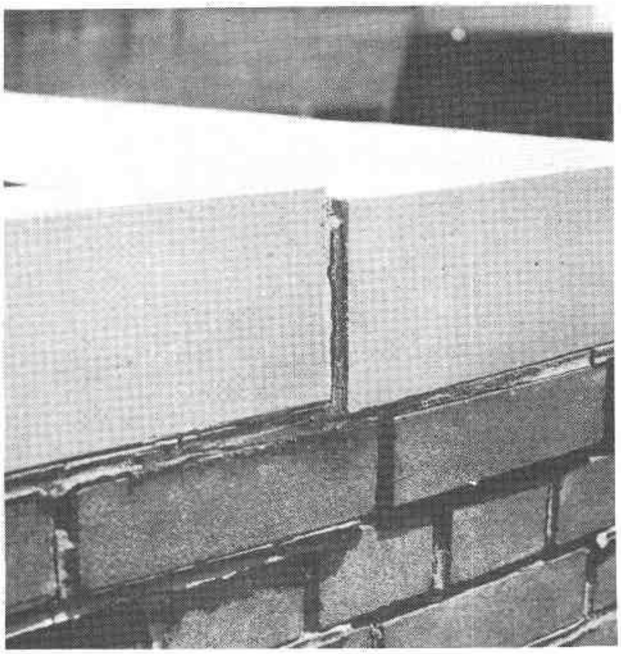


Figure 7 Air leakage from a humidified building caused this damage in one winter.

It will be found, when these principles are applied, that strong continuous exterior cladding rigidly fastened at frequent intervals to the building frame is not necesary, and indeed is not a good way to construct an exterior wall which must meet the thermal, vapour, and air leakage requirements of a humidified building. A structurally self-sufficient interior wythe can be insulated on the outside and the insulation made continuous across the outer faces of the frame, slabs, and partitions. This greatly aids in meeting the requirements already set out. It is then desirable to consider the use of exterior cladding designed on the basis of what is now being called the "open rain screen" approach. Positive control of rain penetration can be achieved, difficult sealing problems can be obviated, the exterior cladding relieved of major wind loads, and the thermal problems associated with the necessary ties greatly relieved.

Conclusion

There is no doubt whatever that failure to follow proper principles in the design of humidified buildings will result in many problems and much expense. The record of difficulties is growing rapidly and there are increasing numbers of buildings of recent construction in which the relative humidities are being reduced in winter to levels below those intended. This is a waste which can be avoided, since it is not necessarily difficult or expensive to design buildings to carry almost any level of relative humidity satisfactorily, provided that the principles are understood and the design of the enclosure is approached in a rational way.