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ABSTRACT

Solar heat gains (radiation) and its effects on the building environment are discussed, in conjunction with the proper and improper use of large glass areas in the exterior walls of buildings in North America. The difficulties of solar heat gain and of controlling natural light and glare are outlined and said to influence building comfort and air conditioning needs. Glass types and methods of construction with glass material are analyzed with regard to construction costs. (TG)

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GLASS WALLS IN NORTH AMERICA

BY

N. B. HUTCHEON

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Glass walls in North America

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by **Dr. N. B. Hutcheon,** *Assistant Director of the Division of Building Research, National Research Council, Ottawa, Canada*

Glass, by virtue of its strong appeal in contemporary building, is the most remarkable of all the common building materials that have come down to us over the centuries. Originally a costly commodity available only to the wealthy, it is now widely available and very extensively used.

Generally of limited structural application in sheet form because of its extreme brittleness, glass has always been prized for the perfection and durability of its surface, but most of all for its transparency to visible radiation. Its traditional use in buildings is for windows to provide natural lighting, but this capability, which is currently challenged both technically and economically by artificial illumination, does not alone explain its present extensive use. Because of its light-transmitting properties it also provides a view of the outside, and it is in this connection, difficult to assess objectively, that the answer to its present popularity must be sought.

The use of glass for architectural purposes has been carried to great lengths in North American building. This has resulted, in the extreme, in exterior walls which are transparent over almost their full area, apart only from the areas occupied by structural members, and in some cases even these have been clad in glass materials. These extreme examples, however, are only part of the general trend to increased glass areas in many types of buildings. There is some evidence even now on which to predict a reversal or rejection of this trend. If this is true the buildings constructed with extensive glass areas may shortly be regarded as old-fashioned but even more serious, many of them will continue to present in their performance throughout the whole of their useful service life weaknesses in design resulting from inadequate attention to the potential difficulties.

Difficulties from solar heat gain and glare

The most serious difficulties arising from the extensive use of glass are associated with increased solar heat gain in summer. Although much of North America may not be regarded as having a hot climate, summer temperatures often approach or exceed the upper limit of comfort as they do in many other countries. Additional heat gains to a building under such conditions complicate the maintenance of comfort conditions. When the use of large glass areas is coupled with the use of air-conditioning, the problems may be largely those of cost, for providing and operating the equipment required to pump out the solar energy which has been admitted. But when large glass areas are employed in a building without proper air-conditioning, and particularly when little attention has been paid to proper solar shading, the results can be most serious. For example, even at latitudes of 50° many buildings of contemporary design, having substantial exposed glass areas but without air-conditioning, will have temperatures in some room adjacent to the solar exposure from 10° C to as much as 20° C higher than those of rooms not so exposed. The indoor conditions thus produced are distinctly uncomfortable at times of high outdoor air temperature and the functions for which the buildings were designed are often seriously affected for substantial periods of time. The most extreme examples have occurred in the case of buildings designed for air-conditioning with windows which were not to be opened, but in which the installation of air-conditioning was delayed or omitted because of cost. Unfortunately buildings with large glass areas without air-conditioning and with fixed windows or otherwise inadequate summer ventilation are all too common.

Even when air-conditioning is provided, so that interior air temperatures can be held to reasonable levels, the use of extensive glass areas may still present many problems. The added cost of the air-conditioning, both initial and operating, may be very great, and the final results may fall far short of the ideal. The limitations in air-conditioning are seldom fully appreciated by those who may be involved in making decisions about it. It is often assumed that air-conditioning, installed at very considerable cost, will naturally and automatically provide the desired comfort conditions everywhere. This is by no means the case. When conditions are subject to rapid and substantial change as a result of changing solar patterns it may often be necessary to employ a more complex system than would otherwise be required, capable of independent adjustment and control from room to room. The cost of air-conditioning to compensate for increased solar loads due to glass areas may thus be increased not only because of increased capacity but also because of the greater cost per unit of capacity of the more complex system.

In current air-conditioning practice, variations in thermal radiation resulting from direct or reflected solar radiation or reradiation can only be compensated for by changes in air temperature and air velocity in order to produce uniform comfort conditions. When substantial variations in radiation intensity exist throughout one room it becomes difficult and costly and it may even be impractical to provide the compensating variations in cooling from one point to another in the same room. The person sitting in the direct rays of the sun may be distinctly too warm while another, at some distance from the window, experiencing exactly the same air temperature, may be quite comfortable. Even when interior shades or drapes are added, as they almost always are, whether planned by the architect or not, the radiation from a hot interior shade may still cause difficulty. When, of course, no air-conditioning is provided and air temperatures are already high, the additional heat gain represented by such radiation may make conditions almost intolerable.

An almost equally serious problem can arise because of variations in illumination when natural lighting is provided by the use of glass. As in the case of thermal radiation, the difficulties increase in proportion to the differences in intensity. Blinds or other shading devices may be demanded by the occupants in order to control glare as well as thermal radiation or, as frequently happens, high levels of artificial illumination may be superimposed in order to reduce the differences, thus adding further to the cooling load and compounding the cost.

Real costs of added glass areas

When the use of increased glass areas results in increased cost of cooling plant, whether initial or operating, or in increased cost for artificial illumination, blinds or drapes, these increases completely from direct solar energy by modest fixed exterior shading devices. Exterior shading on east and west exposures becomes much more difficult. Fixed shading on these exposures cannot be made effective without dominating the appearance of the building and restricting vision, thus often conflicting with the architectural effects being sought. The more adaptable adjustable exterior shading devices have not been widely used and have added mechanical difficulties including those of wind and of snow and ice in more northern areas.

Interior shading by venetian blinds and drapes, though much less effective in reducing solar heat gain than exterior shading, has been widely used. As already indicated, it is often added at the insistence of the occupants whenever it is practical to do so even though not always envisaged in the original design, for control of both light and thermal radiation. The solar radiation absorbed by interior shading results in an increased shade temperature so that it becomes an important radiating source, as well as contributing heat by convection to the room. It may be noted that, since glass will not pass long-wave radiation, only that portion of the transmitted solar energy which is reflected back through the glass is rejected from the room by the drape or blind; the remainder is trapped within the room.

Double glazing with between-glass shading is just starting now to be used and is an improvement over interior shading since a sheet of glass is interposed between the hot shade and the interior. The glass industry has for some time offered heat absorbing glass and this is now widely used. Its action, when used as a single glass is similar to the inside shade, for the radiation which is absorbed heats the glass so that it reradiates long-wave to the room. The heat transfer by radiation and convection from the exterior side is rejected to the outside, however, instead of being trapped by a sheet of glass as in the case of the shade. Again, as in the case of between-glass shading, there is further advantage in using heat absorbing glass as the outer pane of double glazing, since the inner glass is interposed between it and the inside.

Further technical advantages are possible when the outer glass is made partially reflecting rather than absorbing, so that the heating of the glass by absorption is greatly reduced. A thin film of metal deposited on the surface of glass can be used to make it reflecting, but since it is readily damaged it is thus far made available only on the inner surface of the outer pane of sealed double glazing units.

A still more elaborate solution is now offered in the form of durable films having selective emissivities which can be applied to exposed glass surfaces. A sheet of glass can be factory-coated with a film on the outside which imparts relatively high reflectivity to short-wave radiation while the inner surface can be coated with a film having relatively low emissivity to long-wave radiation. Alternatively, these films may be carried separately on the two panes of double glazing. Neither the reflecting glass nor the selective emissivity glass is as yet widely used. Clearly, some of the advantages of these developments could be achieved simply by reducing the area of glass used, and their virtue depends on the demand for a large transparent area providing reduced transmission of both visible and thermal radiation per unit of area rather than a smaller area passing the same total amount.

Prediction of heat gains and resulting temperatures

There is difficulty, not yet satisfactorily resolved, in determining in advance always what the effect will be of adding interior shades, or of changing the type of glass in the windows of a particular building. It has long been possible to calculate with reasonable accuracy the instantaneous heat gain through glass and through other parts of a room enclosure. But if the energy involved falls on the floor or furniture of a room, it does not affect the comfort level of the room until the receiving surface is raised in temperature so that it transfers thermal energy to the air and to other objects, including the occupants. Thus solar energy entering a room represents an "instantaneous heat gain" but does not become a component of cooling load on the air-conditioning plant until some time later, depending on the heat storage capacity of the receiving object. The complication involved in taking storage effects and certain aspects of radiation exchanges into account has made it impractical to use precise methods in design, and cooling plant capacity has usually been estimated by applying storage factors selected on the basis of judgment and experience to calculated instantaneous heat gains. Now that computers are generally available to building designers, they can be used to do the laborious calculations and they offer the possibility of assessing more readily the effects of factors such as interior shades and glass characteristics.

The limitations imposed by the complexity of more exact calculations coupled with the usual practice of using instantaneous heat gains as a basis for estimation has undoubtedly led at times to erroneous conclusions. For example, it can be shown that while the substitution of heat absorbing glass for ordinary glass will always reduce the average cooling load, it may not always result in a reduction in maximum cooling load, and in the case of buildings with large internal heat storage capacity may sometimes result in an increase in the peak capacity required of the system.

The thermal conditions which will be reached as a result of solar effects in a building without air-conditioning are even more dependent upon storage effects than in the case of the air-conditioned building. Consequently no precise estimates are possible without the laborious calculations necessary to take storage effects into account. These are seldom if ever made, and decisions about glass areas in buildings without air-conditioning are almost always made without recourse to any form of calculation as to the thermal conditions which may be produced.

Other considerations

The use of large glass areas poses several other problems, some of which are strongly inter-related. Among these are heat loss and condensation, cleaning, and framing or fixing. A single sheet of glass interposed between indoor and outdoor conditions provides only a small resistance to heat flow. This leads to relatively high heat gains in summer and heat losses in winter. Both of these can be reduced appreciably by the use of double glazing or double windows. There is a strong added reason for the use of double glass in connection with condensation in winter. The low inside surface temperature presented by a single layer of glass drastically limits by condensation the indoor relative humidity which may be carried in cold weather. Condensation as liquid or under more extreme temperatures as frost is unsightly, is a nuisance, may produce wetting and degradation of adjacent construction and interferes with vision through the glass. For these reasons, single glass is seldom adequate, and double glass must be provided in regions having winter temperatures substantially below 0° C.

The use of double glass introduces complications. Condensation between panes becomes a problem and among other things creates the need for frequent cleaning, since repeated condensation-evaporation produces scumming or soiling of flat glass. On the other hand it is impractical or at least very awkward to arrange the large sheets of glass which are commonly used so that they may be manipulated for cleaning between sheets.

These practical difficulties have had two important influences on glass use. They have tended to influence the choice in favour of single glass for many larger buildings and they have given great support to the use of hermetically sealed double glazing wherever double glass is considered necessary. The latter is now widely employed, despite some questionable features of it, including cost, for all sizes of fixed glazing up to very large glass panels, and to a lesser extent in openable windows Sizes up to 204 united inches (sum of width and height) with a maximum dimension of 12 feet are regularly available.

Sealed multiple glazing units

Sealed glazing, though relatively costly, is by no means an ideal solution to the problems of double glazing. The life of sealed units depends, apart from breakage, on the efficacy of the edge seal plus the enclosed desiccant in delaying the onset of condensation between panes. A warranty of five years is usually provided by the manufacturer, but it is in the nature of the product that it will fail eventually. Some units may be expected to last for 10 years or more; other units of recent manufacture have failed in less than 5 years. The prediction, in advance, of the service life which can be expected, constitutes a major practical problem at present. The cost of replacement including the removal of old units can add very considerably to the real cost even if the life expectancy is as much as 10 years.

Contrary to the widely held impression created in part by their promoters, sealed units do not possess thermal properties superior to double windows; they are in fact usually inferior. The air space thickness, which must be kept small to minimize pressure changes with changes in temperature, is actually somewhat less than that for maximum resistance to heat flow. The edge construction, however, is usually inferior thermally to that of the glass-air space combination so that unless very special precautions are taken the edges of the units will present appreciably colder surfaces to the inside air than the glass itself. This places a further limitation on the indoor relative humidities which may be carried without condensation during cold weather, and offsets one of the advantages, now becoming of increasing importance, of using double rather than single glass. Similar difficulties may be encountered with metal sash or frame in which the unit is held, since effective thermal breaks are not readily provided. The use of triple rather than double glazing in sealed units is more costly, and the chances of premature seal failure are increased.

Thermal stresses in glass

Breakage in glass due to thermal stresses is not uncommon. Heating of the central portion of a glass sheet by solar radiation, can produce tensile stresses at the glass edge when the edges are relatively cool because of edge shading or contact with a surround which warms less quickly than the glass. The condition of the edge in respect of stress sensitivity due to rough cutting, nicks or notches will determine the stress required for failure.

Heat absorbing glass, which gains heat more quickly, will normally experience greater temperature fluctuations than other types. When used as the outer sheet of sealed double glazing units, its more rapid and greater expansion produces greater stress on the edge seal, which may promote premature seal failure, or the glass itself may be broken. Opaque glass used as exterior cladding, particularly when backed by insulating materials of low heat capacity, can also be subject to very large temperature differences under solar exposure, leading to cracking difficulties if the edges are not carefully prepared.

Conclusion

The extensive use of large glass areas in the exterior wals of buildings in North America has grown rapidly under the influence of a strong preference for transparent wall sections which has developed largely on aesthetic and subjective grounds. In the face of this strong preference, technical and economic considerations including many of the potential difficulties inherent in the use, or misuse, of glass have often been given little weight.

The real costs of using added glass areas particularly on difficult east and west exposures can amount, in the case of air-conditioned buildings, to several times the initial cost of the glass wall or of the cost of equivalent areas of conventional masonry constructions. Even with air-conditioning the indoor comfort conditions produced have not always been satisfactory, and problems of glare from poor daylighting practices have been common.

The most serious adverse effects of large glass areas upon indoor comfort have been in the case of buildings without air-conditioning. The cost of this in terms of interference with building function has in many cases been substantial. The complications involved in taking into account the thermal storage effects of the building in the calculation of summer indoor conditions have been a serious hindrance to the recognition at the design stage of possible discomfort problems. This has been particularly serious in the case of buildings without air-conditioning in which storage effects are the most important. The approximations used in normal calculations for air-conditioning have not always permitted a proper evaluation of the compensating or corrective measures proposed. These technical difficulties have added to the complications of the studies by which the real costs of added glass areas might be recognized.

Whenever large glass areas are being considered, and it may well be that the preference for them will persist, complete studies should always be made of the effects upon comfort conditions, real costs, and illumination. While it may be impractical to introduce the complex calculations needed for more precise predictions into routine design, more guidance can and must be developed from computer studies of solar heat gain in buildings to aid in improving the designers judgment. The basis already exists for daylighting design and assessment of glare. These improvements are necessary in order that the aesthetic values as well as the traditional use of glass for daylighting may be fully developed and enjoyed without the payment of too high a price.