Weather and building

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Why do you live in a house? The primary purpose of most houses and other buildings is to shelter their occupants and contents from inclement weather. It is true that locks are fitted on doors to discourage thieves or vandals or even persons who might intrude on our privacy, and screens are put on windows to keep out insects, but few buildings in Canada were designed as a protection against people or animals.

Keeping warm and dry are probably the primary aims in constructing most buildings The roof and walls should keep rain (even wind-driven rain) from entering the enclosed space. They should also be reasonably resistant to heat transfer. Having excluded the rain and conserved heat in winter we have also excluded the unwelcome heat of the midsummer sun and the dust and fog and snow that are carried by the wind in different seasons. We have even excluded the light of day and the fresh air, so we must now cut holes in the walls and fit them with glass and blinds or drapes so that we can control the amount of solar radiation and wind that is allowed into our building. Snow will fall on this building and the wind will blow against it. We must ensure that it is strong enough to withstand these forces imposed by the weather.

Let us consider some of these weather elements in more detail.

Temperature

The resistance of the walls of a building to heat transfer and the capacity of the heating system will depend to a large extent on the temperature difference that must be maintained between the inside and outside of the building. The inside temperature that is to be considered comfortable can be arbitrarily set at, say 70°F. The determination of an appropriate value of outside temperature for purposes of design is not so simple. The use of the average temperature during one or more months in the winter would not be satisfactory since the outside temperature would be below the average about half the time. The lowest temperature ever recorded is unsatisfactory for two reasons. In the first place a meteorological station with a short record may reach a much lower temperature in the next few years than it has in the last few. In the second place there is usually no need to design a building so that the inside temperature will never drop below the design value.

The results are not catastrophic if a home or office or shop is uncomfortable for a few hours, or in extreme cases, even for a day or two. This suggests basing the outside design temperature on the average of the temperatures for the coldest day in each year, or on the tenth or fifteenth coldest hour in an average winter month. The choice depends to some extent on the records which are available and on the techniques to be employed in the analysis.

In Canada the hourly temperature readings in January for ten years have been sorted by machine for a number of stations and tables have been drawn up showing the number of hours at each temperature for each station. From these tables a "1% design temperature" can be selected such that one temperature difference that must be main- per cent of the hourly fie at or below this value.* This means that in an average january seven or eight hours out of the total of 744 would have temperatures at or below the 1% design value. Temperatures selected in this way agree reasonably well with the design temperatures arrived at by experience in many localities in Canada and the United States. For dwellings this value is probably unnecessarily low and the corresponding 2½% design temperature is a more reasonable value for general use. This means that in an average january there would be 18 or 19 hours with outdoor temperature at or below the design temperature. If these hours are distributed over a few nights they will result at worst in a few hours slightly below 70°F within the building, most likely in the early mornings.

The problem of keeping a building comfortably cool in summer is similar but, at least in Canada, is less critical. Outside air temperatures rarely reach 100°F. This is only thirty degrees above the arbitrary comfort temperature of 70°F, but heat from the sun can raise building surface temperatures from 20 to 60 degrees above this. Direct sun effects as well as air temperature must be taken into account in determining cooling loads.

Warm summer air can, and usually does, hold much more moisture than cold air and this moisture also has a complex influence on the design and capacity of cooling systems. The most convenient way of obtaining the humidity of the outside air for this purpose is to measure its wet-bulb temperature. Summer design temperatures and summer design wet-bulb temperatures can be obtained in exactly the same way as winter design temperatures. In Canada the hourly temperatures in July are generally used, since July is the warmest month in most parts of the country. The analysis is simplified and the results more easily tabulated if the temperature and wet-bulb temperature can be treated separately. This cannot be done in all countries but over most of Canada the correlation between these primary requirements for any building is that temperatures is close enough to give reasonably accurate results. This means that if a cooling system is designed using the 2½% summer design temperature and the 2½% summer wet-bulb design temperature then for about 18 hours in an average July the combination of temperature and wet-bulb temperature will be more severe than the design conditions.

The cost of operating a heating or cooling system for an average season or for a particular season can be estimated by using observed temperatures in a different way. The energy required will depend on the indoor to outdoor temperature difference and also on the length of time that it persists. The sum of the hourly or daily temperature differences will give the required number of degree-hours or degree-days.

The average temperature inside an unheated building is normally higher than the outside temperature because of direct heating by the sun and heat sources within the building such as persons and machines. For this reason 65°F is commonly used as the base temperature for computing degree-days. Daily mean temperature is usually used in making the calculation, the difference between this. value and 65°F being taken as the degree-days of heating required for the day.

There is much more difficulty in estimating energy requirements for a cooling system for a season, because of the complication introduced by the humidity and by solar and other effects. Degree-days above, say, 70°F could be computed just as easily as those below 65°F but a much more complex analysis including wet-bulb temperature and probably wind and sun effects would be needed to give a useful estimate for an average building. Accordingly, total degree days below 65°F for the winter are generally used as a guide to the heating requirements for buildings, but no simple expression is available for estimating the energy required for cooling.

Precipitation

Precipitation affects the design of buildings in several different ways. One of the primary requirements for any building is that it should keep the interior space dry. All roofs and walls must therefore shed rainwater and design requirements are the same everywhere in this respect. Walls that fail to keep moisture out under severe conditions of wind driven rain may still be considered satisfactory in areas where these conditions are rare. This problem in the case of masonry walls was discussed in **CBD 6**.

The rainwater collected by a sloping roof is concentrated along a line under the eaves. Since this is frequently undesirable it is common to design gutters and down spouts to carry this water away to a drain. The capacity of the drainage system should depend on the maximum rainfall rate. As in the case of design temperatures, however, a failure of the system will not be catastrophic. A rate can be chosen which will be exceeded, on the average, once in two years or once in ten years. In the case of a flat roof draining into the same system as the plumbing fixtures in a building, a failure would be more serious and the maximum rainfall rate expected once in 30 or 100 years might be used.

Rainfall rates must be measured over short periods of time, and the period chosen affects the maximum rate observed. For most roofs the most desirable period would be something less than five minutes but since five minutes is the shortest period for which rainfall is usually reported, it is the best basis for design.

Unfortunately, rainfall intensities for such short periods (five minutes) and for small frequencies (say once in 30 years) have not been available until recently. Roof drainage design is still based on the maximum fifteen minute rainfall once in ten years. This gives a reasonable value for the design of external leaders. To insure against the possibility of flooding inside a building, an internal vertical stack is made several times the size of an external vertical leader designed to carry the same flow of rainwater.

If the drain from a horizontal roof becomes plugged with leaves or snow then rainwater may accumulate on the roof to such a depth as to add considerably to the required strength of the roof. To estimate the probable maximum of this extra load it is necessary to make some assumption about how long the drain might be allowed to remain plugged. One day is a convenient period to consider because one-day rainfalls are readily available. If the rainwater remains where it falls, then each inch of rain will add 5.2 pounds to the load carried by each square foot of roof. Even six inches of rain (which for most parts of Canada is unlikely in one day) will add only 31 pounds per square foot to the load. If the roof has even a slight slope, however, or if adjacent roofs or walls are likely to drain to the flat roof then more serious loads may accumulate.

Unlike rainwater, snow may accumulate for several days, or even for several weeks or months in the colder parts of Canada. The snow may look fluffy and light while it is falling but within a few days it will have settled and become much denser, How much denser is a question that is difficult to answer satisfactorily, because its density may range from about 0.2 to 0.5 while new snow averages about 0.1 (compared to 1.0 for water). Snow densities are not ordinarily measured when snow depths are measured and hence the design snow load must be based on the measured maximum depth of snow on the ground. These maximum depths will usually occur at the end of major snowfalls while a part of the snow is still new and light. It is assumed that the average density of the snow is about 0.2 but it has to be realized that this value may be inaccurate in many cases.

From the annual maximum depths of snow on the ground for fifteen or twenty years, it is possible to estimate the maximum depth for somewhat longer periods. Since an inch of snow represents a load of about one pound per square foot, the depth in inches is numerically equal to the load in pounds per square foot. A number of roof failures have occurred in Canada when rain has fallen into a heavy snow load and increased it. Heavy rains are not uncommon in the late winter and early spring when loads due to snow are at or near their maximum. Since one-day rainfall amounts are readily available, it seems reasonable to add to the snow the weight of the maximum one-day rainfall that might occur at that time of year.

These basic snow loads may have to be adjusted for various reasons. Greater loads are likely to accumulate where snow can drift off one roof onto a lower one, or where a trough occurs. Loads may be reduced on roofs where the snow accumulates less rapidly than on the ground as, for example, on sloped roofs.

Wind

The amount of warm air that escapes through cracks around doors and windows and the amount of cold air or dust that gets in depends partly on the wind speed. Wind speed also affects the relationship between degree-days and the energy required for heating. The relative importance of temperature and wind, however, is largely dependent on the tightness of a building and hence no general formula can be given.

The most important point concerning the effects of wind on building design is that the structure must be strong enough to withstand the strongest winds that might occur. Unlike the failure of a heating system or a roof gutter, the failure of a building to withstand the wind may be catastrophic. The risk must therefore be negligible. The strongest wind that is likely to occur once in thirty years is commonly used but a much less frequent wind would be more logical if it could be estimated reliably.

The strong wind that damages or destroys a building may last for only a few seconds. These strong, brief winds or gusts are only measured at a very few stations and hence, in general they have to be estimated from average wind speeds over longer periods. In Canada the only available wind speeds are averages for one hour. An extensive analysis has been carried out to find the relationship between these hourly averages and the strongest gust speeds. The use of this gust speed may result in the overdesign of large buildings because the time required for the pressure on a building to reach its peak depends on the size of the building.

There is another question to which it is difficult to give a satisfactory answer. How strong are the gust speeds a few hundred feet above the ground? Measurements of gust speeds at these higher levels are much more scarce than those near the ground and hence estimates are correspondingly less reliable. It is generally agreed that average wind speeds over flat and level terrain increase with height approximately in proportion to the one-seventh power of the heights. It is also known that the gustiness, or the ratio of gust speed to average speed, decreases with height, so that gust speeds increase with height in proportion to perhaps the one-tenth or one-eleventh power of the heights. Over rougher terrain the increase of average wind speeds with height is more rapid, or, looking at it from a more logical point of view, the decrease in average wind speed is more rapid as one approaches the ground. The gustiness over rough ground is also greater. The net effect of these two factors on peak gust speeds aloft is hard to judge. It is safe to say, however, that rough terrain, in general, will not increase gust speeds. It is also safe to say that gust speeds will not increase with height as rapidly as average wind speeds. Therefore, if gust speeds are computed for higher levels in proportion to the one-seventh power of the height, the results may not be very accurate but they should be safe, perhaps unnecessarily safe.

Buildings must be designed to exclude certain weather elements such as rain and extreme temperatures and to resist the loads imposed by certain others such as snow and wind. Buildings should also be built of materials that can resist the deteriorating effects of the weather, but that is another story.

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* Values for these and other climatological records for all of Canada are presented in the maps which make up "The Climatological Atlas of Canada". Copies are available from the Division of Building Research, National Research Council at $1.00 per copy.

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