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DESIGN PRINCIPLES

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Although the importance of air tightness has been stressed for the past 25 years in the technical literature dealing with the design of building enclosures, we still construct buildings that provide their owners with excessive energy costs, that make the occupants uncomfortable because of drafts and the infiltration of contaminated air, and that suffer from problems of condensation and the deterioration of their components and materials, which require high costs for repair and maintenance. Air tightness, accordingly, should be the primary objective in the design and construction of walls, windows, floors and roofs of buildings.

The following reasons for the lack of achievement of air tightness in practice may be cited: (1) a lack of appreciation by designers, builders and materials manufacturers of its importance; (2) the assumption that by simply specifying an air vapour barrier the problem is solved; (3) a resignation to the belief that in the practical case air tightness cannot be achieved; and (4) the traditional attitude that some air leakage is necessary in order to provide adequate ventilation.

The notion that air leakage is necessary for ventilation must be dispelled. Instead, air leakage through the building enclosure must be regarded as undesirable, unnecessary and uneconomical, because air leaking into a building cannot be treated or conditioned, nor can its rate of supply or distribution throughout the building be controlled. Similarly, air leaking out of a building not only constitutes a waste of energy but results in condensation and deterioration of the building fabric. Any openings in the building envelope and even those in floors and partitions disrupt the intended operation of heating, ventilating and air-conditioning systems, make it difficult to control noise, and increase the danger of the spread of fire and smoke. In addition, a wall that suffers from air leakage may also suffer from rain leakage if it is exposed to wetting by rain.

In a Canadian Building Digest dealing with fundamental considerations in the design of exterior walls for buildings,[1] Dr. N.B. Hutcheon provided a list of requirements, the first seven of which, termed the "barrier requirements," related to the control of the flow of mass and energy through the enclosure. All of these flows, except for those involving light and solar or other radiation, are influenced by the size, location and distribution of cracks and openings in the building enclosure.

It has been demonstrated that substantial amounts of heat can flow through small cracks and openings. These also provide the primary means for the transport of water vapour into the cold regions of walls, which takes place mainly by the mass flow of air rather than by vapour diffusion through materials. Recent information concerning the control of noise shows that a relatively small opening in a wall can alter considerably its sound transmission properties; thus an opening equal to one one-hundredth of one per cent of the area of the separating element can reduce its sound transmission class by 10 dB. Similarly, openings in a wall affect its fire resistance; thus in the "Standard Method of Small-scale Fire Tests of Walls and Partitions Penetrated by Small Pipes," issued by Underwriters' Laboratories of Canada,[2] one of the failure criteria is the development of an opening "through which hot gases issue at a substantial rate." This can occur when the openings are no larger than 0.1 sq in. (0.6 cm^2).

Air leakage through openings results from air pressure differences created by wind forces, stack effect, and the operation of fans. The pressure created by wind depends on the geometry of the building, as well as the wind's velocity and direction. In most cases, wind pressure will not exceed its stagnation pressure, which is the pressure resulting from the conversion of the wind's kinetic energy to static force. The greatest variation in wind pressure occurs at the edges of a building, while negative pressure or suction is created by vortices and turbulence on the leeward side and over roofs. The amount of suction developed is influenced by the parapet height, and negative pressures several times as large as the stagnation pressure may occur.

The pressure difference across the enclosure due to stack effect results from the difference in temperature of the air inside and outside the building. The exterior barometric pressure varies with height as does the pressure in the building, but the variation with height is less inside because the air is less dense.

When there is little restraint to vertical air flow in the building, an inward movement of air will take place through the openings in the lower half of the building while an outward movement occurs through openings in the upper half of the enclosure. Where the openings in the enclosure are uniformly distributed, the maximum pressure differences across the walls will occur at the bottom and the top, and there will be no pressure difference across the openings at some point near mid-height where the inside and outside pressures are the same, i.e., the neutral pressure plane.

If the building is pressurized by means of fans or blowers, the increased interior pressure will result in the lowering of the neutral pressure plane. An excess of exfiltration over infiltration will take place through the walls; accordingly, the total air exchange will be in excess of that experienced when no fans are used. This approach is sometimes used to eliminate air infiltration in the lower floors, with the object of improving the comfort of the occupants or preventing the entry of contaminated air. Although these objectives may be achieved, such pressurization will not only result in an additional energy loss, but by increasing the quantity of air moving outward through the building envelope, it increases the risk of condensation and deterioration.

If an exhaust system is employed, the decreased pressure within the building results in the raising of the neutral pressure plane. Accordingly, air movement will be inward over most of the wall area, with exfiltration through the exhaust fan and through those portions of the building that are at a higher pressure than outside. This will also increase the air exchange rate and energy loss, with possible discomfort due to drafts on lower floors.

The effect of wind is to create different conditions on the windward and leeward sides of a building. On the windward side, the outside pressure increases with respect to that inside and the neutral pressure plane is raised; accordingly, air infiltration will occur over more of the windward face, while exfiltration occurs only through the area where the interior pressure exceeds that outside. In contrast, on the leeward side, suction is produced, the neutral pressure plane is lowered, and exfiltration occurs over most of the leeward face of the building.

The maximum pressure resulting from stack effect depends on the building height and the temperature difference between the inside and outside. For a 20-storey building maintained at 70°F (21°C) inside, surrounded by air at -20°F (-29°C), a pressure difference equivalent to that produced by a wind of 25 mph (40 km/h) is generated as a result of stack action. Since average wind velocities are usually in the order of 10 - 15 mph (16 - 24 km/h) it can be readily appreciated that stack effect usually overrides wind pressure for high buildings under winter conditions.

Because the pressure differences created by mechanical systems are required for air distribution within the building, and because nothing can be done to change the pressure differences resulting from wind and stack effect, the only solution to minimizing their effects is to reduce the size and number of openings through the enclosure. The objective, therefore, should be to provide as airtight an enclosure as possible. The requirements for fresh air and for exhaust must be met by a separate ventilation system capable of adjustment and control to meet the specific needs of the occupancy.

It has been generally assumed that leakage through the building enclosure occurs primarily at the doors and windows where recognizable joints occur. The Handbook of Fundamentals of the American Society of Heating, Refrigerating and Air-Conditioning Engineers[3] provides information on leakage through doors and windows as well as that occurring between their frames and the wall in which they are installed. Values of air leakage are also provided for masonry construction and wood-frame walls. A masonry wall, for example, will allow substantial air leakage because of the numerous small fissures and openings between the units and mortar; by simply plastering such a wall, however, its air tightness is improved, in some cases by a factor of 100.

Studies undertaken on houses in Ottawa have demonstrated that the air leakage associated with windows and doors constitutes about one fifth of the total, while the leakage through the ceiling and outside walls ranges from 8 to 70 per cent of the total. Studies on large buildings have shown actual air leakage rates far in excess of the values listed by the National Association of Architectural Metal Manufacturers for curtain walls or windows. It is important that all possible leakage paths be identified in order that appropriate drawings, details and specifications can be developed.

Leakage openings can exist in hollow frame walls of wood or metal, either in the framing components themselves or created as the holes and openings cut for services. If cladding materials are not drawn tight to metal studs, leakage paths are formed. In wood-frame walls, subsequent shrinkage of the framing members can result in gaps between these members and the interior or exterior finishes applied to them, allowing air to flow between the wallspaces. Polyethylene film and other membrane barriers have been employed in wood-frame construction to provide a seal over these openings.

Although the plastering of masonry walls provides a substantial degree of air tightness, it is often omitted in such places as the wall area above the level of a dropped ceiling or that behind a radiator unit. In some cases, the furred out vertical shafts provide channels for the movement of air from lower levels into the space above a dropped ceiling.

It should not be assumed that the application of gypsum board or other sheet material to a masonry wall will provide the same degree of air tightness as plaster. Because of the uneven surface of the masonry, intimate contact will not be achieved between it and the surface of the sheet material unless a full bed of adhesive is used. If not, the open space between the masonry and the sheets provides a path for air leakage.

In addition to the openings in a building enclosure caused by expansion and shrinkage of materials, are those resulting from deflection caused by structural forces on the building and its components. Cracks and openings so formed allow air leakage to take place, with the danger of resulting condensation and deterioration.

An important consequence of air leakage is the waste of energy. Extremely leaky buildings, under pressure differences due to stack effect alone, suffer losses due to air leakage amounting to as much as 60 per cent of the total energy required for heating in winter. If such buildings had been constructed to meet the air tightness requirements of organizations such as the National Association of Architectural Metal Manufacturers, the heating load due to infiltration could have been reduced to 6 per cent of the total.

There is merit in improving the air tightness of floor systems and partition walls, particularly in high-rise buildings, because this reduces the pressure difference acting across the exterior walls.

Improved air tightness also assists in the control of ventilation and air distribution, including the control of smoke movement in the case of fire. In addition, it enables a more equitable apportioning of energy charges to be made between the individual units in apartment buildings.

Improving the air tightness of walls, windows, floors and roofs must be regarded as an essential step toward energy conservation in building. Air leakage should never be relied upon for ventilation but should be recognized as an impediment to the proper operation and control of a ventilating system. Such a system, having a specific means of air supply and exhaust, should be required in all buildings to provide an adjustable fresh air supply and used-air exhaust, and should incorporate energy recovery devices. Under such conditions it will be easier to evaluate the actual air leakage characteristics of the completed building, easier to monitor the energy needs associated with ventilation, and easier to predict the performance of the building under the anticipated climatic conditions.

References

1 Hutcheon, N.B. Requirements for exterior walls. National Research Council of Canada, Division of Building Research, CBD 48, 1963.

2 Underwriters' Laboratories of Canada. Standard method of small scale fire tests of walls and partitions penetrated by small pipes. ULC-S115-1977.

3 American Society of Heating, Refrigerating and Air-conditioning Engineers. Handbook of Fundamentals. Issued every four years.