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Vapor Problems in Thermal Insulation

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THERE are many problems associated with water vapor and its migration within building constructions, and a great many of these are related to the use of thermal insulation. Many people in the insulation industry seem reluctant to admit that the use of insulation creates any problems but the simple fact is that thermal insulation applied to a construction results in increased temperatures on the warm, or high temperature, side, and decreased temperatures on the cold, or low temperature, side. This is the inevitable result if the insulation does its job. Any tendency to condensation on the warm side is thereby decreased by the application of insulation and in fact the insulation is frequently used to create this situation and thus to reduce or eliminate condensation of water vapor at these parts of a construction. However, if the vapor density on the warm side is high enough, and if the wall does not provide sufficient resistance to the flow of vapor, migration of vapor through the construction to colder layers on the low temperature side of the insulation can occur. If the density of vapor thus provided at any plane within a construction tends toward a dew-point temperature higher than the temperature at that plane, condensation and subsequent wetting can occur.

It will be assumed that the mechanism of condensation, and the undesirable effects which it can produce are well recognized and need no detailed discussion. The severity of the problems created is, in general, proportional to the rate at which liquid water is formed on or in a construction. It is of interest to note a special feature of the problems associated with condensation formed at temperatures below freezing. The condensate (or sublimate) in such cases is not liquid, but accumulates as frost or as ice. These accumulations in themselves do not always create serious problems, but upon a rise in temperature, melt and thus release over a relatively short time the total weight of water substance which may have been accumulating since the last time the temperature was above freezing. This storage effect at low temperatures gives rise to problems in insulated constructions exposed to prolonged cold weather conditions, even though the rate of condensation is not great and, if occurring at temperatures above freezing, might be tolerated within the construction.

Principles of Vapor Control

The general principles by which condensation within insulated constructions can be controlled have been known and increasingly recognized since 1937 when Rowley, at the University of Minnesota, conducted his outstanding experiments with vapor barriers. These are, to *reduce the amount of water vapor which can enter a construction on the side of higher temperature*, and to *facilitate the escape, on the side of lower temperature, of the water vapor which does enter the construction.*

The entry of vapor at the warm side can be reduced by reducing the density of the vapor to which the construction is exposed at the warm side, or to incorporate within the construction on the warm side of the insulation materials providing resistance to the passage of water vapor. Materials providing high resistance to vapor flow and used primarily for this purpose are called vapor barriers.

Escape of vapor from a construction once it has entered can be facilitated by selecting for the materials on the cold side of the insulation only those which will pass vapor relatively freely. A second, and equally important way is by providing suitable openings by which the vapor which has entered the wall can escape either through or around the parts of the construction which resist its escape to the cold side. Such openings are used to provide a means of escape by diffusion of the water vapor by itself but more frequently they must be arranged to allow air to enter, which will absorb the water vapor and carry it off to the cold side. Such ventilation must be provided only by air drawn from and returned to the cold side, and not by air drawn from the warm side of the construction.

These principles are being applied successfully and without great difficulty to the majority of the cases in which vapor problems in thermal insulation are likely to arise. The difficulties which remain to be overcome are in the development of accurate means of predicting vapor flow and condensation, and in finding suitable ways of dealing with a substantial number of situations in which other requirements make the application of these principles difficult or impossible.

Transport of Vapor by Air Leakage

One of the possibilities for entry of water vapor into the warm side of a construction, and its transport to a cold surface, is frequently overlooked. Although the main mechanism of vapor migration is usually regarded as a diffusion, any substantial movement of air is likely to carry vapor along with it. Normal air pressure differences occurring as

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a result of *chimney action* and wind can cause air to stream through cracks and openings, and to transport water vapor through them at a rate many times that which can occur by diffusion alone. The net result so far as condensation is concerned may be the same as that which would result from a greatly increased diffusion through the materials on the warm side. This effect is analogous to that produced in the case of heat flow by infiltration and by convection, as distinct from conduction. Improperly sealed access doors leading to attics will allow the passage of water vapor along with the upward air leakage at rates capable of producing serious attic condensation. Constructions finished with plaster on the warm side are usually quite air-tight but some dry wall finishes with unfilled joints and with corresponding gaping joints in the vapor barrier will allow sufficient air-and-vapor leakage to cause very serious condensation troubles.

Prediction of Vapor Flow Rates

The calculation of vapor flow by diffusion is usually made on the basis of a simple flow equation based on Fick's law:

$$w = -\mu dp/dx$$

where

w = flow rate.
μ = coefficient of vapor permeability.
dp/dx = vapor pressure gradient.

This equation is analogous to that used in the calculation of heat transmission $q = -k\ dt/dx$ and vapor flow calculations can be made in an entirely comparable manner. The permeability coefficient can be established from suitable tests, as is the coefficient of thermal conductivity in the case of heat flow. However, there is one important difference of great practical importance. The permeability coefficient, μ, unlike k, is not a constant for any given material but can be greatly influenced, in a complicated way, by temperature and vapor pressure.

Despite the great difficulties inherent in dealing rationally with moisture migration over the full range of conditions likely to be encountered, many useful calculations may be made on the basis of the simple flow theory. The permeability coefficient is reasonably constant for a few materials and for many others it does not vary widely over a range of conditions resulting in low or moderate relative humidities. Useful results can be obtained in many cases by the judicious use of coefficients obtained from relatively simple dry and wet cup tests. These tests can also be used as a basis for a useful comparison of the moisture transmission characteristics of materials, and they have for some time been successfully employed as a basis for selecting vapor barrier materials.

Criteria for Vapor Barriers

Calculations made independently a number of years ago by Miller and by Babbitt indicated that for certain insulated wood frame constructions exposed to severe winter conditions, with moderate humidities carried on the warm side, additional resistance by way of a vapor barrier was required on the warm side of the insulation in order to prevent serious condensation. They were able to establish also that this vapor barrier should not pass more than about 0.7 grains of moisture per (sq ft) (hr) (in.) of mercury, (permeance 0.7 perms) when tested under certain conditions.

In the United States *HHFA* has set a limit of 1 perm for vapor barrier materials, and these materials as installed must meet a limiting permeance of 1¼ perms. In Canada a limit of 0.75 perms for vapor barriers has been widely used and has proved to be satisfactory in practice, even under severe winter conditions. No Canadian cases are known in which a vapor barrier meeting this requirement and properly installed with lapped and clamped joints in insulated wood frame walls of average construction in dwellings has failed to give adequate control over vapor flow under winter conditions. Canadian experience has indicated the desirability of avoiding any membranes on the cold side which have an effective permeance less than 3 perms, and the value of using separate and continuous vapor barrier membranes even when vapor resistant membranes are provided with the insulating batt or blanket.

Moisture Storage an Advantage

Joy was the first to point out an important factor in condensation control, the ability of the sheathing material to sorb and to store water. With a 0.75 perm vapor barrier in insulated wood frame dwelling construction, the moisture entering the wall in one winter season will be about 0.1 pounds per sq ft. This amount of water can be taken up by 1-in. wood sheathing with a rise in moisture content of only 3 percent, to be given off under more favorable escape conditions the following summer. Constructions possessing this feature may be particularly desirable under severe and prolonged winter conditions when diffusion through the outer covering is greatly reduced as a result of lowered temperatures, and there is a tendency for condensation to be collected over long periods as frost or ice.

Cold Storage Construction

The general principles of vapor control already outlined apply also to low temperature storage constructions. They differ from heated buildings mainly in the direction of vapor flow which is inward, requiring that the vapor barrier be placed on the outside, and in the long periods of continuous operation over which moisture entering the construction can accumulate. The selection of vapor barriers likely to provide very low permeance and good durability will usually be justified.

Reversed Flow Conditions

Special problems in vapor control can arise in cases in which there is a reversal of vapor pressure gradient, and therefore of the direction of vapor flow, on a cyclical basis. Cool-storage buildings operating at temperatures of about 40 F experience such reversals in vapor flow from winter to summer, and pose an awkward problem since the vapor barrier ought to be on the outside in summer and the inside in winter. Attempts to seal a wall construction by vapor barriers on both sides will seldom be fully effective since the barriers can never be perfect and the air between them, expanding and contracting from winter to summer to winter, causes a breathing action which may result in some accumulation of moisture. In special cases vents provided on both sides of a wall may be alternately opened and closed from season to season. Unless the reversal is particularly severe, a single vapor barrier may be located for the more severe condition with some condensation in the opposite season being accepted.

Special Problems in Metal Buildings

Serious condensation problems have been experienced in many metal buildings insulated and heated for winter occupancy. Metal ribs often provide heat paths through the insulation, producing surface condensation. Interior finishes and vapor barriers are frequently installed so as to permit excessive outward leakage of warm moist air. The exterior metal skins restrict the outward diffusion of any vapor which does enter the construction and are incapable of storing any moisture which may collect. Difficulties can be eliminated by careful design and installation.

Insulated Roof Problems

By far the most important building moisture problem economically is that encountered in roofs consisting of impermeable coverings laid over insulation on flat decks or slabs. The roof covering is, for all practical purposes, a perfect vapor barrier and effectively traps any moisture which is present at the time of construction or which subsequently enters the insulation as vapor from inside the building. Since air trapped between the vapor barrier and the roof covering will undergo substantial pressure changes as a result of daily or seasonal temperature changes, or even as a result of alternate sunshine and rain in summer, it is seldom possible to prevent breathing of the space occupied by the insulation. This action should be recognized and provision made for it by way of vents to the outside, properly shielded against entry of rain and snow. Good vapor barriers are essential for proper protection of insulation and roofing in the case of any moderate- or high-humidity occupancy.

Conclusion

Control of the flow of water vapor so as to avoid condensation can be achieved without great difficulty in many applications of thermal insulation. Such control is needed for the proper functioning of thermal insulation and in order to avoid excessive deterioration of the adjacent construction as a result of wetting. The principles and practice are now well established for many situations but there are some which present special difficulties. Moisture migration within materials and particularly the way in which this is related to temperature gradient and to heat flow require a great deal of further study and research before any great refinement in the prediction of moisture conditions within building constructions can be achieved.