by parging or a good exterior grade sheathing paper on the outside of the insulation can be effective in such cases.

Vapor which diffuses inwards under cooling conditions adds to the cooling load. Vapor barriers in walls installed for winter conditions are a help in reducing this. However, if condensation does occur on the back of a vapor barrier installed on the inside of the insulation, the latent heat which is then released on the inside of the insulation may add to the heat gain through the wall.

REFERENCES

[1] S. C. Hite and J. L. Dray: *Research in Home Humidity Control* (Purdue University, *Engineering Experiment Station Research Series* No. 106, November 1948).

[2] S. C. Chang and N. B. Hutcheon: Dependence of water vapor permeability on temperature and humidity (ASHAE TRANSACTIONS, Vol. 62, 1956, p. 437).

[3] F. A. Joy and E. R. Queer: Permeance measurement improved by special cell (ASHVE TRANSACTIONS, Vol. 55, 1949, p. 377).

[4] F. A. Joy, E. R. Queer, and R. E. Schreiner: *Water Vapor Transfer Through Building Materials* (Pennsylvania State College, *Engineering Experiment Station Bulletin* No. 61, December 1948).

[5] J. D. Babbitt: The diffusion of water vapor through various building materials (*Canadian Journal of Research*, February 1939, p. 15).

[6] F. A. Joy and D. R. Fairbanks: Effect of unbalanced air pressure on permeance (ASHAE TRANSACTIONS, Vol. 62, 1956, p. 451).

[7] R. M. Barrer: *Diffusion In and Through Solids* (Cambridge Press, London, 1951).

[8] L. V. Teesdale: *Remedial Measures for Building Construction* (*U. S. Forest Products Laboratory Report* R1710, 1947).

[9] F. B. Rowley, A. B. Algren, and C. E. Lund: *Methods of Moisture Control and Their Application to Building Construction* (University of Minnesota, *Engineering Experiment Station Bulletin* No. 17).

[10] H. J. Barre: *The Relation of Wall Construction to Moisture Accumulation in Fill-Type Insulation* (Iowa State College of Agriculture and Mechanic Arts, *Agricultural Experiment Station Bulletin* No. 271, 1940).

[11] P. F. McDermott: Moisture migration: a survey of theory and existing knowledge (*Refrigerating Engineering*, August 1941, p. 103).

[12] R. I. Wray and A. R. Van Vorst: Permeability of paint films to moisture (*Industrial and Engineering Chemistry*, Vol. 25, 1933, p. 842).

[13] R. R. Britton and R. C. Reichel: *Water Vapor Transmission of Building Materials Using Four Different Testing Methods* (*U. S. Housing and Home Finance Agency Technical Bulletin* No. 12, January 1950).

[14] E. R. Bell, M. G. Seidl, and N. T. Krueger: Water-vapor permeability of building papers and other sheet materials (ASHVE TRANSACTIONS, Vol. 57, 1951, p. 287).

[15] Value from unpublished texts of Pennsylvania State College Experiment Station.

[16] F. A. Joy: Basic concepts of water vapor migration and their application to frame walls (*ASTM Special Technical Publication* No. 119, 1951, p. 2).

[17] *Condensation Control in Dwelling Constructions* (U. S. Housing and Home Finance Agency, 1949).

BIBLIOGRAPHY

H. W. Wooley: *Moisture Condensation in Building Walls* (*National Bureau of Standards Report* BMS 63, December 14, 1940).

F. B. Rowley, A. B. Algren, and C. E. Lund: Condensation of moisture and its relation to building construction and operation (ASHVE TRANSACTIONS, Vol. 45, 1939, p. 231).

P. D. Close: Permissible relative humidities in humidified buildings (ASHVE JOURNAL SECTION, *Heating, Piping and Air Conditioning*, December 1939, p. 766).

F. B. Rowley, A. B. Algren, and C. E. Lund: Condensation within walls (ASHVE TRANSACTIONS, Vol. 44, 1938, p. 95).

H. Edenholm: Moisture movement and moisture distribution in the walls of buildings (*Meddelanden Fran Statens Forsknings-kommitte for Lantmannabyggnader* No. 5, 1945, p. 53, available as Technical Translation TT-361 from the National Research Council of Canada, 1952).

J. D. Babbitt: *Physics of Condensation in Buildings* (*National Research Council of Canada Bulletin* No. 2).

L. V. Teesdale: Comparative resistance to vapor transmission of various building materials (ASHVE TRANSACTIONS, Vol. 49, 1943, p. 124).

Durability of moisture-resistant membrane materials in contact with the ground (Housing and Home Finance Agency, *Housing Research* No. 4, October 1952, p. 23).

Proposed method of test for water vapor transmission of building materials utilising the Penn State-Armstrong cell (*ASTM Bulletin* No. 215, July 1956, p. 63).

Heat and water vapor transmission apparatus for insulated panels (National Bureau of Standards, *Technical News Bulletin*, November 1954, p. 157).

F. A. Joy and A. W. Sherdon: Automatic permeance measurement by the permeometer (ASHAE TRANSACTIONS, Vol. 59, 1953, p. 435).

F. B. Rowley: A theory covering the transfer of vapor through materials (ASHVE TRANSACTIONS, Vol. 45, 1939, p. 545).

F. G. Hechler, E. R. McLaughlin, and E. R. Queer: Simultaneous heat and vapor transfer characteristics of an insulating material (ASHVE TRANSACTIONS, Vol. 48, 1942, p. 505).

J. A. Paxton and N. B. Hutcheon: Moisture migration in a closed, guarded hot plate (ASHVE TRANSACTIONS, Vol. 58, 1952, p. 301).

C. G. Gurr, T. J. Marshall, and J. T. Hutton: Movement of water in soil due to a temperature gradient (*Soil Science*, November 1952, p. 335).

W. A. Hadley and Ray Eisenstadt: Moisture movement in soils due to temperature difference (ASHAE TRANSACTIONS, Vol. 59, 1953, p. 395).

K. R. Solvason: Moisture in transient heat flow (ASHAE TRANSACTIONS, Vol. 62, 1956, p. 111).

H. F. Winterkorn: Fundamental similarities between electro-osmotic and thermo-osmotic phenomena (*Proceedings 27th Annual Meeting*, Vol. 27, Highway Research Board, 1947, p. 443).

S. C. Chang and N. B. Hutcheon: Performance of desiccants in the dry pan test for water vapor permeance of membranes (*Canadian Journal of Technology*, September 1953, p. 175).

F. A. Joy: Thermal conductivity of insulation containing moisture (*ASTM Special Technical Publication* No. 217, February 1957, p. 65).

J. S. Cammerer: The effect of moisture on heat transmission through building and insulating materials (*Wärme und Kältetechnik*, September 1939, p. 126, available as Technical Translation TT-317 of the National Research Council of Canada, 1952).

H. B. Jesperson: Thermal conductivity of moist materials and its measurement (*Journal of IHVE*, August 1953, p. 157).

D. Krischer: Heat conductivity and water vapor diffusion in materials for insulation against cold (*Wärme und Kältetechnik*, 1941, 43(0), p. 2, translation available from British Building Research Station as Library Communication No. 492).

D. A. De Vries: The thermal conductivity of soil (Mededelingen van de Landbouwhogeschool te wageningen, 1952, 52(1), p. 1, translation available from British Building Research Station as Library Communication No. 759).

C. H. Johansson: Moisture transmission and moisture distribution in building materials (*Wärme-Ventilations-Sanitelstek*, 19: 67, 1948, available as Technical Translation TT-189 from the National Research Council of Canada).

J. D. Babbitt: The movement of moisture through solids (*ASTM Bulletin* No. 212, February 1956, p. 58).

J. R. Philip and D. A. De Vries: Moisture movement in porous materials under temperature gradients (*American Geophysical Union Transactions*, April 1957, p. 222).

CHAPTER 11

INFILTRATION AND VENTILATION

Causes of Infiltration, Infiltration Due to Wind Pressure, Infiltration Due to Temperature Difference, Sealing of Vertical Openings, Infiltration Measurement, Natural Ventilation, Wind Forces, Temperature Difference Forces, Heat Removal, Effect of Unequal Openings, Combined Wind and Temperature Forces, Types of Openings, General Ventilation Rules, Ventilation of Animal Shelters, Garage Ventilation

INFILTRATION is the air leakage through cracks and interstices, around windows and doors, and through floors and walls. Its magnitude depends on the structural design, workmanship, and condition of the building. The rate of infiltration cannot be controlled by the inhabitants of the building to any considerable extent. Natural ventilation is the controlled displacement of air through openings, such as windows, doors, and ventilators as well as through combustion heating devices.

CAUSES OF INFILTRATION

The air leakage which takes place through various apertures in buildings must be estimated in heating and cooling calculations and enough heating or cooling capacity provided to offset the heat lost or gained by the air leakage. The rate of air flow into and out of a building depends on the magnitude of the pressure difference between the inside and outside of the structure and on the resistances presented to this pressure difference. The pressure difference exerted on the building walls by the air may be caused either by wind or by a difference in density of the air inside and outside the building. The effect of the wind depends on the interrelation of the speed and direction of the wind and the exposure of the building. The effect of the difference in the density of the air depends on the magnitude of the indoor-outdoor temperature difference, the height of the rooms, the shape of the openings, and their elevation in the room or building. The effect of the difference in density is often referred to as the chimney or stack effect. The pattern of air flow through any part of the structure depends on both the pressure difference and the openings. In general, when the pressure difference is the result of wind pressure, air will enter the building through openings in the windward walls and leave through openings in the leeward walls or through ventilating ducts in the roof. When the pressure difference is caused by the indoor-outdoor temperature difference the flow will be along the path of least resistance from inlets at lower levels to outlets at higher levels in a heated building or in the opposite direction for an air-conditioned building.

An exact estimate of the amount of infiltration under *design* conditions is difficult to make. The complicating factors include (1) variations in building construction, particularly as to width of crack or size of openings through which air leakage takes place; (2) variations in wind velocity and direction; (3) exposure of the building with respect to air leakage openings, and with respect to adjoining buildings; (4) variations in outdoor temperatures which influence the chimney effect; (5) relative area and resistance of openings on the windward and leeward sides, and on the lower floors and on the upper floors; and (6) influence of a planned air supply and the related outlet vents. Tight construction is essential for preventing large heat loss due to infiltration.

In view of the meager information available on infiltration, a cooperative investigation was undertaken in 1954 in which the infiltration rates of residences were obtained by actual measurement.[1, 2] In 1956 a study was started at the ASHAE Research Laboratory to obtain additional information on infiltration through building entrances.[3] These studies are yielding quantitative information on factors affecting infiltration rates, but more data are still needed.

INFILTRATION DUE TO WIND PRESSURE

The wind causes a pressure to be exerted on one or two sides of a building. As a result, air comes into the building on the windward side through cracks or porous construction, and a similar quantity of air leaves on the leeward side through like openings. In general, the resistance to air movement is similar on the windward to that on the leeward side. This causes a building up of pressure within the building, and a lesser air leakage than that experienced in single wall tests as determined in the laboratory. It is assumed that actual building leakages, owing to this building up of pressure, will be 80 percent of laboratory test values. While there are cases where this is not true, tests in actual buildings substantiate the factor for the general case. Mechanical ventilating systems are frequently designed to produce positive or negative pressures in an enclosure, which are greater or lower than prevalent wind pressures. In such designs, if the specified rate at which air is to be supplied to, or removed from, the enclosure by positive means, exceeds the infiltration rate, it is common practice to use the greater value in determining the heating capacity to warm the outdoor air.

Infiltration Through Walls

Data on infiltration through brick and frame walls are given in Table 1.[4] The brick walls listed in this table are walls that show poor workmanship, and which are constructed of porous brick and lime mortar. For good workmanship, the leakage through hard brick walls with cement-lime mortar does not exceed one-third the values given. These tests indicate that plastering reduces the leakage by about 96 percent; a heavy coat of cold water paint, 50 percent; and three coats of oil paint carefully applied, 28 percent. The infiltration through walls ranges from 6 to 25 percent of that through windows and doors in a 10-story