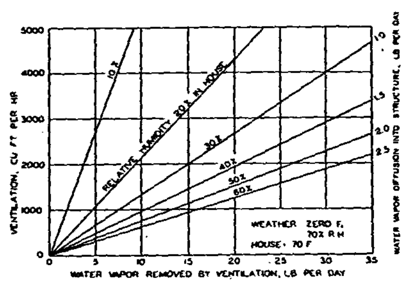
fundamental principles that should be followed. First, the vapor barrier should be placed as near to the warm surface of the wall as practicable. Second, it should be continuous with no direct openings through the barrier. Good workmanship and application are very important. Workmanship that leaves two openings through the barrier, or around its margin, at different levels, connecting air spaces at only slightly different temperatures, leaves a path for thermosyphon air rotation which will transport large amounts of water vapor from the warmer space to the colder. If a membrane barrier is used back of the plaster or interior finish, its joints should be made over some solid framing member, and not between the studs or in similar places. Usually a two-inch lap over a framing member will make a sufficiently tight joint when the interior finish is applied. Such a lap, however, without backing would not be adequate. Barriers attached to the warm side of insulation should form a continuous unbroken membrane over the entire insulated area. Edges should be lapped over framing members; ends of strips should be fastened by lapping over plates or headers. All openings for electrical fixtures and joints around window and door casings should be carefully sealed. Holes accidentally made in the barrier should be sealed.

2. *Ventilation of Living Space.* The second measure listed for the control of concealed condensation is ventilation of the house. This measure is obviously necessary as an accompaniment to a vapor barrier since, if the barrier blocks entrance into the walls, the water vapor must be removed by other means. No great volume of air change is necessary, however, and normal infiltration alone is frequently all that is required in winter weather.

The effectiveness of ventilation is shown in Fig. 7, which also shows the small amount of water vapor escaping into the barrier-equipped, well-insulated walls and ceilings (2000 sq ft) of a typical small dwelling, the floor being neglected. Evidently, ventilation of 2000 cfh will remove 21 lb of vapor per day with the relative humidity at 40 percent, while at the same time 1.5 lb escapes into the structure. The total vapor production (22.5 lb) is a typical amount. Double glass will be barely safe from visible condensation as will be seen in Fig. 4. By reference to Chapter 6, 2000 cfh appears to be near the minimum for odor control, and ventilation would have to be higher when cooking is done. By reference to Chapter 11, it appears that usual infiltration will normally supply the necessary air change, but that supplementary ventilation may be necessary in kitchen and laundry for proper vapor control and for the reduction of peaks in relative humidity that would otherwise occur in those areas.




(Vapor Barrier, 1 perm; Wall and Ceiling Area 2000 sq ft Insulated)

Fig. 7 .... Water Vapor Balance in a Dwelling

3. *Ventilation of Structure.* The third measure listed for the control of concealed condensation is ventilation of the structure itself. It is effective in certain cases especially as a supplement to warm-side vapor resistance which is considerable but not of itself fully adequate. Air from outdoors is used. The vents must be shielded from the entrance of rain and insects.

Attics and crawl spaces may be considered as parts of the structure, and for these portions ventilation is practically a necessity. Attic ventilation has long been an established practice but its effectiveness is likely to be diminished by the newer practice of adding insulation to ceilings. Insulation requires added ventilation which in turn necessitates adequate insulation. The recommended ventilation shown in Table 3 for dwellings[17] is based on such insulation. The *net area* refers to the total of all openings free from obstructions. The use of louvers and 8-mesh screen (usually recommended) requires a gross area 2.25 times that listed. In Zone I of Fig. 6 a ceiling vapor barrier is recommended for all constructions. It is also necessary that stray openings from walls into the attic, or around a loose fitting attic door be avoided. The *stack effect* allows a large inflow of warm air from the dwelling, transporting much vapor to a danger area. More desirable ventilation of the house can be arranged.

Crawl spaces under dwellings where the earth is damp and uncovered require a high rate of ventilation. At least four openings, one at each corner, as high as possible, should be provided.[17] Their total net area may be calculated by the formula:

Table 3 .... Recommended Good Practice[17] for Loft and Attic Ventilation[a]

| |
|---|
| *Flat Roof—Slope Less than 3 Inches in 12 Inches* |
| Condensation Zone I[c]: Total net area of ventilation should be 1/300th[b] distributed uniformly at the eaves *plus* a vapor barrier in the top story ceiling. Free circulation must be provided through all spaces. |
| Condensation Zone II and III: Same as for Zone I. |
| *Gable Roof—Slope over 3 Inches in 12 Inches* |
| Condensation Zone I: Total net area of at least 2 louvers on opposite sides located near the ridge to be 1/300th[b] *plus* a vapor barrier in the top story ceiling. |
| Condensation Zone II: Same ventilation as for Zone I. A vapor barrier is not considered necessary. |
| Condensation Zone III: Same as for Zone II. |
| *Hip Roof* |
| Condensation Zone I: Total net area of ventilation should be 1/300th[b] with 1/600th[b] distributed uniformly at the eaves *and* 1/600th[b] located at the ridge with all spaces interconnected. A vapor barrier should also be used in the top story ceiling. |
| Condensation Zone II: Same ventilation as for Zone I. A vapor barrier is not considered necessary. |
| Condensation Zone III: Same as for Zone II. |
| *Gable or Hip Roof—With Occupancy Contemplated* |
| Condensation Zone I: Total net area of ventilation should be 1/300th[b] with 1/600th[b] distributed uniformly at the eaves and 1/600th[b] located at the ridge with all spaces interconnected. A vapor barrier should also be used on the warm side of the top full story ceiling, the dwarf walls, the sloping part of the roof, and the attic story ceiling. |
| Condensation Zone II: Same as for Zone I. |
| Condensation Zone III: Same as for Zone I except that a vapor barrier is not considered necessary if insulation is omitted. |

[a] It is recognized that in many areas increased ventilation may be desirable for summer comfort. For winter comfort, insulation is recommended between a living space and a loft or attic ventilated at these rates.

[b] Refers to area enclosed within building lines at eave level.

[c] The zone numbers refer to Fig. 6.



$$a = \frac{2L}{100} + \frac{A}{300} \tag{10}$$

*where:*

$L$ = the perimeter of the crawl space, linear feet.

$A$ = the area of the crawl space, square feet.

$a$ = the total net area of all vents, (or the gross area if a 4-mesh screen is used) square feet.

This ventilation is usually sufficient but cools the first floor so much that insulation is needed. A better treatment is a cover on the damp ground. This cover may be a concrete slab, or merely heavy roll roofing laid on a graded surface with its edges lapped 2 in. (but not necessarily cemented). With this barrier, the vent area may be reduced to 10 percent of that calculated by Equation 10.

In building walls, cavity ventilation can be applied in a moderate climate as the sole vapor control system. In general, however, air passages in walls designed to remove an unrestricted vapor supply are unduly large and may waste considerable heat. On the other hand, a barrier as the only control measure would, in some cases, require so high a resistance as to be impractical. Ventilation of the structure in conjunction with a vapor barrier, is a procedure with important applications, but its general utility has not been fully investigated. Ventilation is most effective when each structural space has a clearly defined air passage with an inlet and outlet. In walls a small thermosyphon effect may be utilized by locating one vent at the bottom and one at the top of each space.

The best time to vapor-proof a building is during its construction. After a building is completed, ventilation of the occupied space is the most easily applied of the three basic control measures. Paint that is chosen for its low vapor permeance can be applied as a barrier on the interior with good results, care being taken that all areas, including parts of partitions and ceilings which offer an indirect vapor path to the cold wall, are covered. Ventilation of the wall cavity is effective in certain cases especially to supplement the foregoing measures. When such venting is required, each cavity space isolated by framing should be separately vented with an inlet and outlet judiciously placed, to accomplish proper air change.

## CONDENSATION IN COOLED STRUCTURES

Water vapor is sometimes an even greater problem in cooled than in heated structures, but the basic facts of its migration and condensation on cold surfaces are the same. Refrigerators, cold pipes, and cold vessels all require insulation and should be provided with a vapor barrier. The barrier, as always, should be placed on the warm side of the insulation and as close as possible to the warm surface of any enclosure. It resists the movement of water vapor toward the colder parts of the structure, and its job is even more exacting than that required in residential construction. In the case of an insulated cold pipe line, the process is likely to be uninterrupted for years and there is no chance for vapor that enters the insulation to dry out periodically. Also, no vapor can escape from the cold side, if this is a metal (vapor tight) pipe. For such an application vapor control requires insulating material that is itself very highly resistant to water vapor or a coating whose permeance is the minimum obtainable, not over 0.1 perm. Metal coverings are desirable but difficult to apply.

Similar considerations apply in the case of cold rooms whether constructed inside a heated building or as a separate building. In the latter case, cold rooms operating above freezing provide some periods of vapor reversal in winter but such drying can be of little help. Refrigerators, however, if lined with cement or other vapor permeant material, will allow slight amounts of vapor to pass and to that extent reduce the accumulation of moisture that may have penetrated the barrier. While this is helpful, emphasis must be placed on an adequate warm-side barrier not greater than 0.1 perm.

Summer air cooling for comfort does not normally create serious vapor problems in exterior walls and ceilings. Normally the cooled air is little, if any, colder than the dew point of the outdoor atmosphere and there are no areas of condensation. The design dry-bulb and design wet-bulb temperatures in common use as given in Table 2, Chapter 13, tend to bear this out. For the 315 cities in the United States, for which design values are given, only 78 have design wet-bulb temperatures in common use over 75 F. Outdoor dew-point temperatures, especially peak values, may exceed the design wet-bulb temperatures in common use, but these will seldom be greatly in excess of 75 F for any prolonged period of time. Condensation within exterior walls which are exposed to indoor air at 75 F will seldom be as serious as for the winter condition.

A vapor barrier to prevent condensation within exterior walls under summer cooling conditions would normally be located on the outside of the insulation, whereas the location for the winter condition is on the inner side. The use of vapor barriers at both locations is not without difficulty because they not only restrict the entry of moisture into the insulation but also restrict the escape of any moisture. It is generally considered best in dwelling construction to locate the vapor barrier for the more serious case of condensation in winter, and to disregard the summer case even when some condensation may be expected. The corresponding situation in cold-storage buildings in which there may be a much more serious reversal of vapor flow conditions from winter to summer poses a wall design problem that has not yet been fully resolved.

Some observations made by the National Research Council of Canada, but not yet publicly reported, would indicate that serious wetting within walls can occur in summer under special conditions. The walls of test huts of brick masonry, but finished inside with strapping, insulation, vapor barrier, and plasterboard interior finish, were opened during a sunny period that followed a rain. Extensive wetting was observed in the insulation, and particularly on the back of the vapor barrier. The brick wall which was unusually absorptive had taken on substantial quantities of water during the period of rainfall. Subsequent heating by the sun had driven the moisture as vapor into the wall where it condensed and caused serious wetting. The construction in question did not have protection for the strapping and insulation in the form of parging or paper on the inside of the brick. Walls having absorptive exterior coverings capable of absorbing and storing considerable quantities of water during a rain and providing little resistance to vapor flow into the insulation from the outdoors, may experience serious interior wetting by condensation under such unusual conditions. No wetting occurred in a construction similar to that described above when a saturated sheathing paper was used between the insulation and the brick. It would appear that the provision of moderate resistance to vapor flow such as that provided