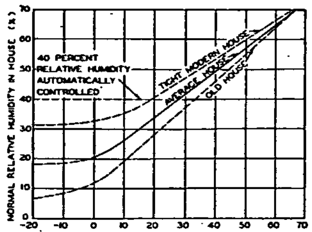
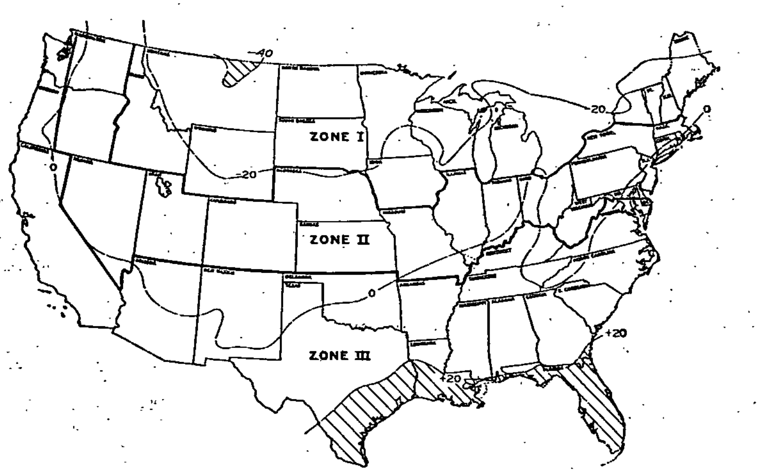


Fig. 5 .... Relative Humidity in Dwellings

The resulting balance may be expressed in terms of relative humidity if the inside temperature is 70 F. The relative humidity in heated buildings covers nearly all of the possible range. In zero weather it may be only 10 percent in an office, and 85 percent in an industrial plant where humidification is required for a process, or where vapor release is incidental to a process. In residences the relative humidity in cold winter weather ranges from 10 percent to 60 percent, the latter figure applying to a very small, crowded and unventilated dwelling. A 40 percent level is considered representative of a substantial number of modern tightly constructed small houses although the average house relative humidity is probably below 25 percent. Surveys in residences show that the relative humidity increases as would be expected in warmer weather. Fig. 5 represents the results of one such survey.[9]

When water vapor is allowed to enter a wall and condensation occurs on its outer cold elements, it appears as frost or liquid. If the weather temperature rises frequently, frost melts and becoming liquid, is likely to penetrate capillary materials like wood, or run down when the surface is non-absorbing or is already saturated with water. In weather that is continuously cold for a long period, the frost may build back into a cavity or fibrous insulation and, when it reaches a warmer plane, will run to lower, cooler levels where it forms a mass of ice. Water seepage to the weather side may occur harmlessly in masonry walls when the weather is above freezing but water seepage into the building must obviously be avoided. In typical frame construction with wood sheathing which has large water absorbing capacity, seepage is rare and occurs only after a long period of steady cold weather. More generally, moisture accumulates in wood sheathing and siding through the colder months and reaches a peak in late winter, after which the drying of spring and summer completes the annual cycle.[17] The average winter temperature and its duration are factors in the condensation problem. In Fig. 6 the map of the United States is divided into condensation zones based on winter weather conditions. The solid lines separating the zones follow state lines, and are those recommended by the Housing and Home Finance Agency for the guidance of owners, builders, and architects.[18] The dashed lines are the -20 F, 0 F, and $+20$ F isotherms of winter design temperature taken from The Guide, 1958, Fig. 1, Chapter 12. It will be noted that there is reasonably good correlation between the zones determined by the two sets of lines. Zone I roughly includes those areas where the design temperature is -20 F or colder; Zone II those for which the design temperature is zero to -20 F, and Zone III those at zero and warmer. Within each zone, similar degrees of condensation trouble are to be expected, and similar corrective measures apply.

In roofs, the condensation problem is much the same as in walls. The roof covering may be even more resistant to the escape of vapor than wall coverings such as paint; and while paint is likely to be ruptured by excessive moisture, no such relief occurs in roofs. Thus roofs furnish conspicuous examples of rapid decay in lumber.



Zones Include Areas with Design Temperatures about as follows: Zone I, -20 F and lower; Zone II, 0 F to -20 F; and Zone III, above 0 F. Note that cross hatched areas are outside of Zones I and III.)

Fig. 6 .... Condensation Zones in the United States

In crawl spaces over uncovered damp ground, a large water evaporation sometimes occurs and causes condensation on the outer ends of floor joists and other members that are below the floor line and near the outdoors. Water vapor from the crawl space may also enter walls, be transported by rising air in a stack effect, and even reach the attic by this route when the wall structure permits. Ventilation, as discussed later in this chapter, is an important correction factor in these cases.

Insulation in a wall or roof reduces heat loss and lowers the temperature of the outer elements of the structure, thus increasing the possibility of condensation if the vapor path to the cold surface is not blocked. Since low vapor resistance is a characteristic of fibrous insulation, the needed vapor resistance must be provided by other means. It is to be noted that in typical residential conditions, condensation does not occur in fibrous insulation itself, except when frost has formed on sheathing and gradually built backward among the fibers. Wet insulation may result from this condition or from liquid condensation seeping down from a higher level.

CONTROL OF CONCEALED CONDENSATION

An excessive accumulation of moisture in walls (or roofs) can be prevented by one or more of the following measures: (1) providing a vapor and air barrier to limit vapor entrance into the wall, (2) ventilating the building to reduce vapor pressure therein, or (3) ventilating the wall cavity to remove vapor that has entered.

1. *Vapor Barrier.* A vapor barrier is the principal and most obvious correction, but each measure is more effective if aided by the effect of another. In habitations, some ventilation of the living space, either incidental or planned, is necessary. Also, a small amount of cavity ventilation is essential in cases where the vapor inflow is not completely stopped and the moisture storing capacity of the outer wall elements is slight. This applies to some prefabricated designs using metal siding.

Vapor-barrier sheets are often built into the wall near the warm surface. In wood frame walls they may be applied to the inside surface of the studs. They are sometimes attached to the warm side of the insulating materials, or they may be applied on the cold side of plaster base materials. Special designs may be attached like wall paper to the inside of the wall, when satisfactory from the decorative viewpoint. Sheet barriers, such as polyethylene films and laminates containing asphalt, paper and metal foil, so placed that they are not too cold, may also be used.

The interior wall board or finish material may itself be vapor resistant, or a barrier coating may be applied to its concealed side if that side will not be too cold. The interior finished surface may be coated with a suitable paint having the required vapor resistance and also serving as the decorative finish, or it may be covered by another coat.

A paint coat on the interior finish, though of adequate resistance, is not likely to be as effective as a sheet barrier properly applied during the wall construction. This applies especially to houses of more than one story having cavities in ceilings which open into the outside walls. Such cavities allow vapor entering the ceiling to diffuse or be transported to the cold areas. Stoppage of this path is difficult and requires normally the painting of the ceiling as well as the walls. Similar treatment may be required on internal partitions, or at least the first stud space adjacent to a cold wall.

The necessary barrier resistance depends on a number of factors. When the vapor flow occurs in annual cycles as in heated buildings, the requirement is not as exacting as it is for a cold storage room where there is no chance for drying out an accumulation of moisture. In a heated structure covered on the outside with materials highly resistant to water vapor such as paint or roll roofing, the winter season is a time of moisture accumulation in the cold outer elements and their safe moisture holding capacity is an important factor in determining the barrier requirement.[17] A house without sheathing requires a better barrier. A prefabricated design with only a sheet of metal outside of the insulation, requires a very high resistance barrier on the warm side. Materials such as plastic faced sidings, aluminum siding and decorative metal panels may present problems of condensation directly behind the cold side finish. The interior vapor pressure and the length and severity of the winter are also important.

For typical frame dwellings with wood sheathing and siding in the northern United States, a barrier permeance of one perm or less has been found satisfactory. There are cases, however, in residential construction where a one perm barrier would not be adequate and there are also many industrial applications in which a very much higher vapor resistance is required. In any event, the choice of an adequate barrier implies that its permeance be definitely established. The usually accepted test procedure for this purpose is a dry method at a temperature of 70 F to 80 F. If obtainable at reasonable cost (including good application), a barrier better than required should be chosen for any construction. Despite the theoretical possibility of safely discharging some vapor through a wall, a higher-than-minimum permeance is not preferred.

An exact statement showing which buildings require a vapor barrier is not readily formulated. However, in view of the distressing results its omission may bring, it is tentatively recommended that the walls of every well constructed modern dwelling include a vapor barrier when the construction includes any material that would be damaged by moisture or its freezing. This applies to all condensation zones in Fig. 6 when the U value for the wall is lower than 0.25 Btu per (hr) (sq ft) (F deg), and it applies in Zone I and Zone II to walls of higher transmittance.

In applying vapor resistance to a wall, there are certain 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 convective 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 2-in. 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. Avoid stapling insulation flanges to the sides of the framing. If this must be done, a separate vapor barrier, such as polyethylene plastic sheeting should be installed over the entire wall for best results. 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