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**CONDENSATION IN WALLS
AND ATTICS**

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Condensation or moisture accumulation within walls and in attics or roof spaces has become a subject of considerable concern to many home owners and prospective builders, especially in the states north of the Ohio River. This problem is not new; it has been known for many years that condensation occurs under certain conditions in houses and barns, particularly in localities subject to severe winter weather, but only recently has it become a general problem, particularly in the better class of construction. There have been so many cases in recent years that any prospective builder may hear about ice in attics, stained ceilings and side walls, plaster becoming loose, ruined decorations, decayed side wall, roof, studs, and sheathing, floors that have bulged up, outside paint failures, and numerous other manifestations of moisture resulting from condensation. While no doubt there is some exaggeration as to the extent of damage, there is also much truth. Such instances of damage have been occurring frequently in the last few years, particularly after the cold winter of 1935-36. In some instances the damage is visible, whereas in others it is concealed in the walls and unknown. Even new houses under construction in cold weather often show evidence of moisture, especially if plastered during the late fall or winter months.

Obviously the question arises as to why we hear so much more about this condition now than we used to just a few years ago. The answer is relatively simple. During the last few years there has been a marked tendency on the part of the architects, builders, and home owners to improve homes both new and old with the idea of increasing the comfort of the occupants and decreasing operating expenses. Prominent among these improvements are the increasing use of storm sash, insulation, weather strips, calking around windows and doors, and other means of decreasing heat loss and wind infiltration. Because of the tighter construction the normal humidity or vapor pressure within a house so constructed is higher than in houses less tightly constructed. In addition, as a health and comfort measure the normal humidity is usually augmented by evaporating water or some other means of winter air conditioning. Improvements that add to comfort and health are worth while and should not be discouraged, but it so happens that they introduce the unanticipated moisture problem just-described.

A certain amount of water vapor is always present in the atmosphere. The maximum amount of water vapor that can be present depends upon the temperature of the air, being greater at higher temperatures. Air that is completely saturated with water vapor is said to be at its dewpoint temperature and its relative humidity is 100 percent. Air not completely saturated with water vapor is above its dewpoint temperature and its relative humidity is less than 100 percent. Adding water vapor to unsaturated air without changing the temperature of the air will increase the relative humidity and raise the dewpoint temperature. Removing water vapor will have the opposite effects. Raising the temperature of air without changing the amount of water vapor in it will decrease its relative humidity. Lowering the temperature will increase the relative humidity till the dewpoint temperature is reached. Further lowering will cause progressive condensation of water vapor from the air.

The use of relative humidity as a measure of the amount of water vapor present in a given atmosphere is not satisfactory because this relationship varies with the temperature. Hence it is more practical to use the vapor pressure of the water vapor for this purpose, since it is a direct measure of the proportion of vapor present in the air. This property is usually expressed in terms of inches of mercury.

At zero degrees F. air will hold very little water vapor. If saturated air from out of doors at zero degrees temperature is introduced without adding moisture into a house heated at 70° F., the relative humidity will be about 5 percent. However, there are sources of moisture within an occupied house, such as cooking, evaporation from plants, laundry work, respiration, and bathing, so that the normal relative humidity within a home may be about 10 to 15 percent when the outdoor temperature is zero. Evaporation from a furnace pan or water pans on radiators may increase the humidity to 20 percent or more. This means, of course, that the vapor pressure inside of the home will be higher than that outside. Because of the higher water vapor pressure within doors there will be a constant out leakage of water vapor, the amount depending upon the tightness of windows and doors, the permeability of the wall materials, and upon other factors. If doors and windows are loose, water vapor will pass out readily and if tight the leakage will be minimized.

Winter air conditioning means, among other things, maintaining a humidity in the home at some established value intended to be better suited to health, comfort, and protection of woodwork than the normal humidity just described. With winter air conditioning the relative humidity may often be 40 percent or higher. The humidity may be controlled automatically with hygostat, in which case it will be relatively constant, but without such control the humidity may fluctuate considerably.

The effect of the humidity or vapor pressure on condensation can be understood by examining figures 1 and 2. Figure 1 illustrates a typical frame wall of lath and plaster, studs, sheathing, sheathing paper, and wood siding. Figure 2 illustrates a wall similar in all respects except that the

stud space is filled with insulation. For purposes of illustration the following examples have been chosen: One indoor temperature of 70° F.; three outdoor temperatures of 20° F., 0° F., and -20° F.; and three indoor relative humidities of 40 percent, 30 percent, and 20 percent. When the temperature of the room side of the sheathing is above the dewpoint temperature in the room no condensation can take place within the stud space. When, however, the sheathing temperature falls below the room dewpoint a different set of conditions prevails. If, in figure 1, the lath and plaster offered no resistance to the passage of vapor, condensation could take place on the sheathing with the latter exactly at the room dewpoint. The amount of condensation would be limited only by the ability of the sheathing to function as a condenser and the permeability of the sheathing to water vapor. Since the lath and plaster do offer some resistance to the passage of vapor, the vapor pressure within the stud space will be less than that within the room whenever there is vapor movement through the lath and plaster. Actually, therefore, condensation cannot take place within the stud space until the sheathing temperature is appreciably less than the room dewpoint. When condensation is actually taking place on the sheathing, the vapor pressure within the stud space will be largely determined by the sheathing temperature and will, in general, correspond rather closely to saturation pressure at this temperature. The three jagged lines marked "temperature" show the temperature gradients from one side of the wall to the other for the three chosen conditions. The three dashed horizontal lines marked "dewpoint temperature" serve to locate the dewpoint temperatures for the foregoing three indoor relative humidities. The water vapor pressures corresponding to these dewpoints are also marked on the respective lines.

Comparing figures 1 and 2, it is at once evident that, within the stud space, the temperature gradients are much steeper in figure 2 than in figure 1, and that the respective sheathing temperatures are much lower in figure 2 than in figure 1. This results from the addition of insulation in figure 2. Because of the lower sheathing temperatures condensation will occur on the sheathing with lower room humidities when insulation is used than when it is not used. Conditions within the walls are actually more complicated than the drawings and examples indicate, because they are not static, and matters of heat balance and rates of water vapor movement and air movement have important effects upon what goes on.

Referring again to figure 1: When the relative humidity within the house is 40 percent the vapor pressure is approximately 0.295 of an inch. The temperature gradient through the wall when the outside temperature is 20° below zero intersects the room side of the sheathing at about 26° above zero and, assuming saturated air at this point, the vapor pressure there will be only about 0.137 of an inch. This difference in vapor pressure will cause vapor to move from the room through the plaster to the stud space and condensation will develop in this space. This condensation will eventually appear as frost or ice on the sheathing, which is below the freezing point. The still lower temperature and vapor pressure on the inner face of the sheathing paper will cause some of the remaining moisture vapor to move from the inside face of the sheathing to the colder face of the paper but as the

resistance to such movement is greater through the sheathing than through the open stud space the rate of vapor movement will be correspondingly small. However, with a rise in outside temperature the ice may melt and some water may be absorbed by the sheathing. Some may even run down inside the wall. The better grades of sheathing paper commonly used are very vapor resistant and very little vapor will pass through, but with changing outdoor temperatures when cold weather is followed by mild temperature the ice that forms between the sheathing and the paper may melt behind the paper, run down to a horizontal joint where some may work through and wet the siding. This is one source of moisture that may contribute to paint failures.

The same general principle of vapor movement exists where fill insulation is used. The insulation 'itself' is not resistant to vapor movement and the bulk of the condensation appears on the inside face of the sheathing. However, in the insulated wall the resistance to heat loss offered by the insulation results in a much lower temperature at the sheathing line, consequently the sheathing is below the dewpoint temperature at much higher outside temperatures than is the case in uninsulated walls. This fact in turn very greatly increases the amount of condensation that may collect, since periods of extremely cold weather, such as are required to cause condensation in uninsulated walls, are of relatively short duration but there may be a total of several weeks during the winter when the outside temperature is low enough to cause condensation in insulated walls.

There are a number of types and kinds of insulation on the market and the potential buyer often hears that certain types "draw water" and become wet. This is not true. Such insulation, because of its efficiency in reducing heat loss, lowers the temperatures within the wall and thus sets up the condition that increases the amount of moisture that may accumulate. Once understanding the conditions that cause the moisture it is also possible to provide means of prevention as discussed later.

The conditions that cause condensation in side walls also occur in attics or under roofs, modified more or less by any ventilation that may be provided or that may occur naturally. Roof condensation is reported far more frequently than side wall condensation, not necessarily because it occurs more frequently but rather because it is more likely to be seen by the occupants. For example, in a pitched roof house having, say, fill insulation in the ceiling below the attic, condensation may develop during a severe cold spell on the under side of the roof boards, forming as ice or frost. When the weather moderates, or even under a bright sun, the ice melts and drips on the attic floor, leaks through and spots the ceiling below. Often such spots are assumed to be roof leaks and cause owners and contractors considerable unnecessary expense in attempting to waterproof a roof that is not leaking. If the attic has adequate ventilation little or no trouble will occur but adequate ventilation is sometimes difficult to attain, and tends to increase the heat loss.

The movement of water vapor is independent of air movement to the degree that no general circulation of air is necessary to carry the vapor into the wall. The vapor actually moves by diffusion from zones of higher vapor pressure to zones of lower vapor pressure. In fact plaster is very highly resistant to air infiltration even when under a pressure equivalent to a wind velocity of 15 miles per hour but no such pressure exists within a house. Vapor, however, will move very readily through plain plaster but is retarded somewhat by paint coatings and other surface treatments. Other types of wall surfacing materials, such as plywood, fiber boards, and plaster boards are also permeable to vapor and here again the surface decorating material has more or less effect on the resistance. In the case of plywood the type of glue used is also a factor, the phenolic resin glues being much more resistant than soy bean and casein glues to the passage of vapor.

Moisture accumulation within a wall like those illustrated in figures 1 and 2 is affected by five factors:

1. Outside temperature and humidity.
2. Efficiency of insulation.
3. Inside atmosphere (temperature and humidity).
4. Resistance of outer wall to vapor movement.
5. Resistance of inside wall to vapor movement.

As the outside temperature and humidity cannot be controlled and as insulation adds to comfort, health, and fuel economy, methods of prevention are limited to the three other factors. Some authorities believe that indoor humidities low enough to preclude the possibility of moisture accumulation are undesirable both as a factor of health and comfort and in preventing the over-drying of interior woodwork and furniture. It is possible, of course, to compromise and carry somewhat lower humidities during very cold weather than are maintained during moderate winter weather and thus reduce the amount of moisture that would accumulate as condensation. It is also possible to so construct walls that the vapor could pass outward through sheathing and sheathing paper and escape through openings in the outside wall covering or be carried away by ventilating the space between the sheathing and outside finish. Standard construction does not lend itself to this method of moisture elimination. Either the inclusion of ventilating holes in the side wall material or a ventilating space would require more or less modification of the conventional construction. One possible method for wood siding would be to place 1 by 2 inch furring strips over the sheathing, thus obtaining a vertical ventilating space approximately of $3/4$ of an inch which should be open to the outside at both the bottom and top of the wall so that air could enter at the bottom and pass out at the top. The openings could be concealed behind but not covered by mouldings or other treatment at the water table and cornice. Similar ventilation could be adapted to stucco, brick, and stone exteriors. With this method the sheathing paper should be of a type that passes water vapor readily, such as slaters felt. During periods of protracted cold weather it is quite possible that moisture would accumulate in the wall faster than it could pass through and be removed by ventilation, hence the ventilation method might not assure complete protection. So far, the possibilities in this method have not been thoroughly investigated by the Forest Products Laboratory.

Attics under pitched roofs can often be ventilated either through windows or louvered openings, ventilators in the roof, or openings in chimneys. Wood shingle roofs when laid on roof boards that are separated about 2 inches will often allow enough ventilation in the attic to eliminate the moisture problem. Flat roofs are more of a problem. Where the ceiling joists or supports and roof joists or supports are separated enough to allow a free circulation of air, and where sufficient openings and vents are installed a fair degree of ventilation can be obtained. Often the space under flat roofs is not sufficient to obtain adequate circulation.

The most positive, and least expensive, method of control so far experimented with at the Forest Products Laboratory is the use of vapor resistant barriers at or near the inner face of the wall and under ceiling joists under the attic. In houses under construction this barrier can be attached to the inner face of the studs after the walls have been insulated and before lathing or finishing the wall on the inside. In houses already plastered the barrier can be some suitable material or treatment applied to the interior surface of exterior walls. While it might appear on first thought that such a barrier should be 100 percent resistant, actually, however, it is not practical to obtain 100 percent efficiency. With a suitable barrier, however, the amount of moisture entering the wall is so small that it will not raise the moisture content to a degree that is objectionable.

The Forest Products Laboratory has been making tests on the vapor resistance of various materials used in wall construction and also on many materials that might be used for moisture barriers. Although these tests are still under way and have not covered all possible materials, enough information is available to permit the selection of a number of materials that are highly resistant to the passage of water vapor. Among these are (1) asphalt impregnated and surface coated sheathing paper, glossy surfaced, weighing 35 to 50 pounds per roll of 500 square feet; (2) laminated sheathing paper made of two or more sheets of kraft paper cemented together with asphalt; (3) double-faced reflective insulation mounted on paper. The water-vapor resistances of these three materials, as measured at the Laboratory differ considerably one from another. Unfortunately, the work has not progressed far enough yet to enable a definite statement of the precise degree of vapor-resistance required for any specific set of conditions. Most of the discussions and recommendations in this preliminary article are based upon a climate such as that of Madison, Wis., and upon plastered wood construction. The recommendations have not yet been subjected to actual service tests, and may have to be modified as time goes on.

The barrier when located as described on the warm side of the dewpoint position resists the passage of moisture while it is in the form of vapor and therefore before it has a chance to condense into water. Hence there is no hazard of water forming behind the plaster or other interior wall finish. The barrier also prevents moisture from getting into the wall or attic space during the construction period, particularly during the plastering operation.

Such vapor barriers should be applied vertically on side walls with edges lapping on the studs after the insulation is installed and before lathing. Horizontal joints should be made only where backed up with a plate or header. The barrier should be brought up tight against electric fixture outlets, air registers, door and window frames, and other similar openings. If wood lath, metal lath, or other types requiring a plaster key are used the paper should be applied slightly loose so that the plaster can push the barrier back to form the key. Where the ceilings below the attic or roof are insulated the barrier should be applied in a similar manner.

Walls finished with such materials as plywood, fiber board, plaster board, and the like, should also have the barrier as described. Sheathing paper when used outside of the sheathing in combination with the moisture barriers described should be water resistant but not very vapor resistant so that the small amount of water vapor that may leak through the barrier can escape outward. Slaters felt meets this requirement. Quite possibly the sheathing paper could be omitted entirely; and it is conceivable that the omission would actually result in a drier wall. Further experiments will have to be made before this point can be definitely settled.

Some kinds of mineral wool are relatively resistant to water absorption, others are treated to make them resistant to wetting by water. This property, while desirable, does not make these materials resistant to the passage of vapor. Therefore they should not be considered a source of protection against condensation.

Some types of mineral wool have a vapor-resistant paper back attached to the batt. Tests to date indicate that none of these papers has a vapor resistance equal that of the 50-pound sheathing paper previously mentioned. They are sufficiently resistant, however, to be of definite help in keeping the insulation and the wall dry and to warrant proper care in installation. The wool batt is made to fit between standard stud, joist, and rafter spacing with tabs on the paper which extend out from the batt and are tacked to the studs or rafters. The batt may be cut or forced back to obtain the tabs at the end of the batt. Where the spaces are not standard between studs, such as occurs around windows, doors, and dormers, particular care should be taken to obtain good joints even if it is necessary to use one of the barriers previously described.

Blanket types of insulation are also available where the insulation is enclosed within a heavy paper covering treated with asphalt. This paper covering is a fairly effective vapor barrier but not so effective as the 50-pound sheathing paper. It is important that this type of insulation be carefully installed so that vapor cannot work through around the edges. The tabs should be nailed to the face of the studs with the insulation looping loosely inward away from the inner face of the wall or if installed between studs it should be fastened in place with wood strips.

Fiber board sheathing is often used as a substitute for wood sheathing and because of its lighter structure it offers more resistance to heat loss than a similar thickness of wood. It may be used either with or without other insulation. When used with other insulation the methods of protection suggested should be followed. When no other insulation is used the need of a moisture barrier is much less, just as with wood sheathing.

Many materials embodying the principle of reflective insulation are in use but opportunity for observation and tests has been limited. One type having metal foil attached to both sides of a heavy sheet of paper is very resistant to vapor and another type composed of a strong paper faced on both sides with metal oxides is also very effective in resisting vapor transmission. Data upon the comparative vapor resistance of these papers and many other materials are to appear in a forthcoming article.

The practice of installing insulation in existing houses, some of which have been built for many years, is becoming general, adding both to summer and winter comfort of the occupants. The occurrence of moisture or condensation in these older houses after insulation is quite uncommon, largely because such houses are not so tight as new houses, windows fit less snugly and probably have no weather strips. Under such conditions the normal humidity is lower. Occasionally, however, these older homes will also show evidence of moisture accumulation and generally when the occupant has made an effort to increase the humidity above normal. Some of the companies that insulate existing houses take off a portion of the outer wall covering and cut a large number of openings in the sheathing through which the insulation is blown and replace the outer covering without filling the holes in the sheathing. These openings allow more or less ventilation and should be helpful in allowing vapor to escape outward. Some companies include some form of attic or roof ventilation as part of their contract.

Positive protection for existing buildings that have a moisture problem or where it is proposed to install winter air conditioning may require some type of barrier on the interior face of exterior walls and on the ceilings below the roof. Ordinary paints of the flat wall, or lead and oil types do not seem to offer the resistance desired but two coats of aluminum paint appear to offer excellent resistance and permit almost any subsequent method of decoration desired.

The question sometimes arises as to the possibility of summer cooling causing condensation in walls. This is very unlikely because the inside temperatures are seldom more than 15 degrees below outside temperatures so that the possibility of condensation would only occur during periods of extremely high humidity outside. Such a condition would be of rather short duration and would be unimportant.

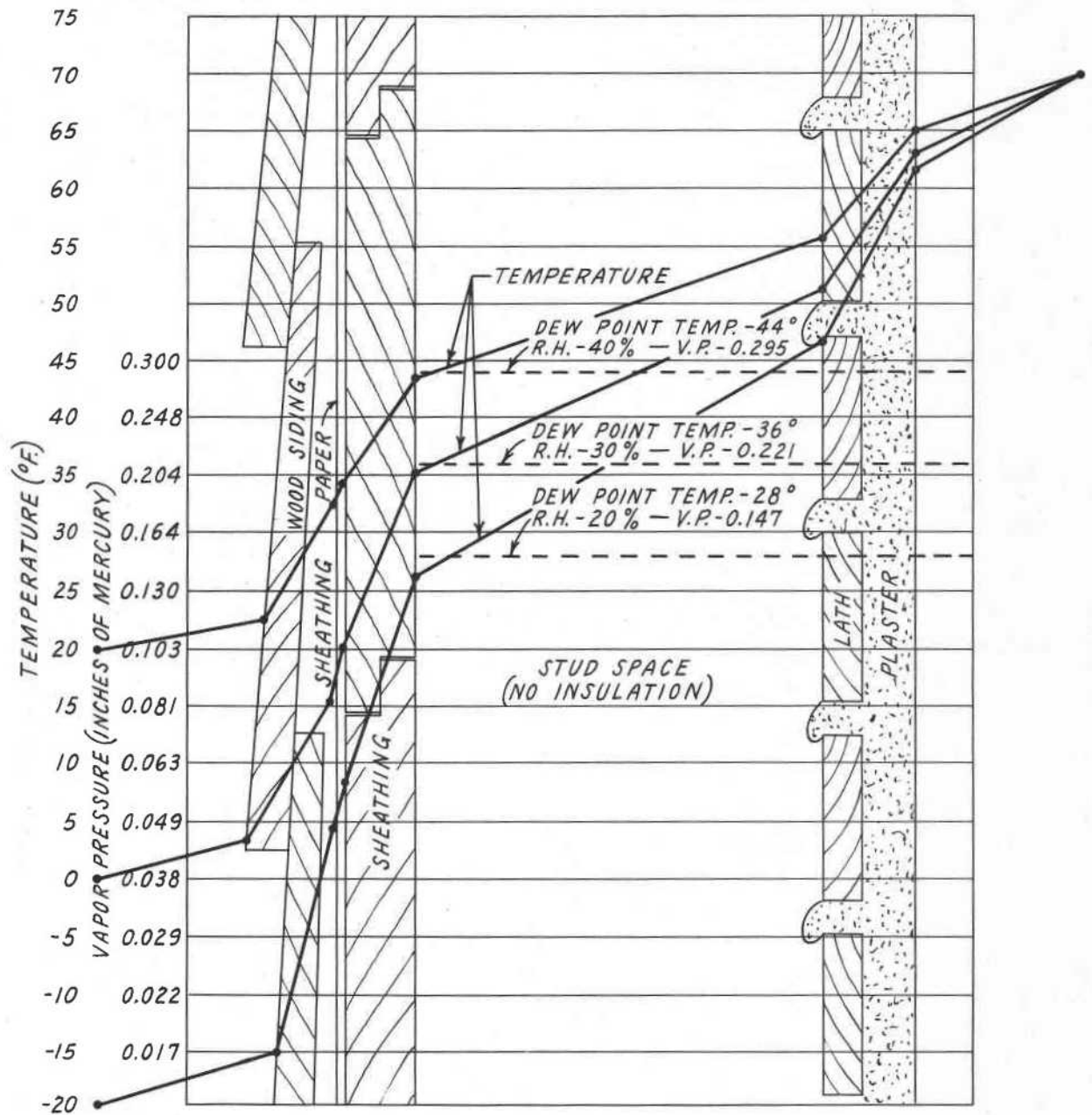
General Recommendations

For new construction it is recommended that a suitable vapor barrier be installed on the side wall studs and below the ceiling insulation and that some attic ventilation also be provided. This will not only protect the house for normal humidities but should prove ample protection in case winter air conditioning is installed. Further, it offers protection during the construction period, particularly if plastering is done in cold weather.

For existing houses that have been or are to be insulated, and where humidities during cold weather are low, attic ventilation alone should be adequate. Should evidence of moisture appear in mild weather following a cold period, cut off all possible sources of humidity for the balance of the winter and some time later in the following summer, after the moisture has had time to disappear, coat the exterior walls and the ceiling below the roof insulation with two coats of aluminum paint after which redecorate as desired.

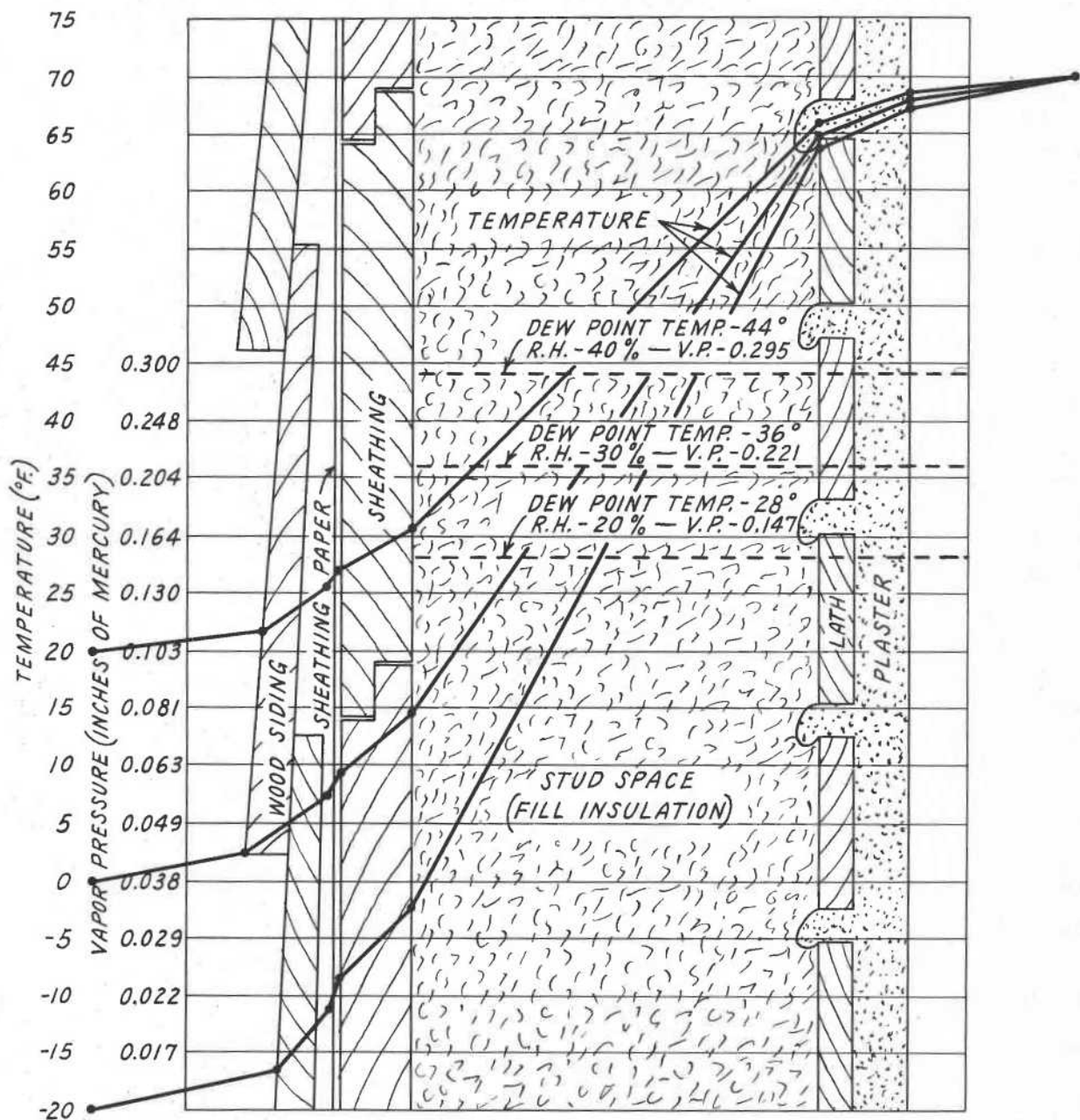
For existing houses that are equipped for winter air conditioning follow the foregoing suggestions and during periods when outside temperatures are below 15° F. carry relative humidities not higher than 30 percent, and in sub-zero weather reduce to 20 percent relative humidity.

The suggestions offered here are based upon tests now under way at the Forest Products Laboratory combined with observation and experience in occupied homes. As these tests and observations are continued and additional information becomes available more specific recommendations for protection against moisture condensation will be forthcoming.



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FIG. 1



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FIG. 2