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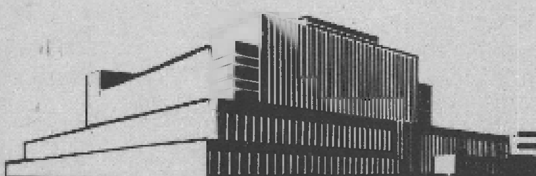

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

CONDENSATION PROBLEMS IN FARM BUILDINGS[1]

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Condensation of moisture in farm buildings housing livestock has always been a problem in the winter in the colder portions of the country and is responsible for much of the maintenance expense on these structures. This problem is not peculiar to farm buildings, but occurs in varying degrees of importance in houses, factories, creameries, cold storage warehouses, freight cars, and even in air conditioned railway coaches. For each type of occupancy or condition there is, of course, some method of control or prevention, sometimes simple, sometimes complex. In houses under construction it is relatively simple and inexpensive to include vapor barriers that will control the condensation problem to a satisfactory degree. In factories and mills manufacturing certain products high humidities are a requirement and here the problem is often more complicated. Methods applicable to one type of occupancy do not necessarily fit other types. Consequently, each type must be considered separately and methods of control developed suited to the conditions involved.

Since this discussion applies to farm structures other types will not be considered except insofar as they may be used to illustrate a principle. A review of the principles involved is, of course, necessary to analyze the problem and to intelligently discuss the possible methods of control.

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. By definition, air that is completely saturated with water vapor is 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

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

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 without changing the amount of water vapor will increase the relative humidity till the dewpoint temperature and saturation are reached. Further lowering of the temperature 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 amount 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 this temperature be introduced into a barn, without adding moisture, and raised to 45° F. its relative humidity would be about 13 percent. If there were no source of moisture present within the barn the vapor pressure inside would be equal to that out of doors. However, in dairy barns, for example, the animals supply a large amount of water vapor to the air by transpiration and exhalation, and there are numerous other sources such as manure, urine, drinking water, and feed. Actually the humidity in a good tight barn may be and usually is very high during cold weather. It has been estimated that a milch cow of average weight will give off 12 to 18 pounds of moisture per day, an average of 4,375 grains per hour. At 45° F. saturated air will hold only about 3-1/2 grains of water vapor per cubic foot. A few cows would, therefore, very quickly saturate the air in a barn if there were no means of escape for the moisture, and if this temperature were maintained. However, with a higher temperature and a higher vapor pressure in the building than outside, vapor escapes outward through cracks and crevices, by direct ventilation, and to some degree by passing through the walls of the structure. Furthermore, in the colder weather, vapor may condense as liquid water or as frost upon and within the walls and ceiling. When, at constant temperature within the building, the losses described equal the supply the internal relative humidity remains constant; but if the supply exceeds the losses the relative humidity approaches saturation.

The principle of ventilation as a means of removing the vapor is well understood, and barns generally are provided with some form of ventilating system, not only to remove the vapor but also to purify the air. Provision for ventilation varies widely, sometimes limited to cracks and crevices, sometimes to a roof vent over the hay mow, but in the better types of modern barns inlet and outlet flues and ducts, including dampers for control, are provided. During most of the year, including the milder winter weather, ventilation can be counted upon to keep the barn normally dry. During cold weather the problem becomes complicated by the fact that the ventilation must be reduced to prevent the barns from becoming too cold; at the same time windows, exterior walls, ceilings, and roof surfaces become colder and act as condensing surfaces. Condensation develops on surfaces that are below the dewpoint of the atmosphere and since the humidity in stock barns is quite high a surface that is only a few degrees colder than the atmosphere may be below the dewpoint. For example, at 45° F. and 90 percent relative humidity the dewpoint is about 42° F. Should any portion of the walls, ceilings, roof or glass surface be below 42° F. condensation would develop on such surfaces. Since the animals furnish the source of heat and since a large part of the heat lost is radiated through the surfaces mentioned, these surfaces are bound to have a lower temperature during cold weather than the general barn temperature. The effect of the humidity or vapor pressure on condensation may be understood by examining Figures 1, 2, and 3. Frame walls have been selected for examples, but the same principles apply to masonry and steel construction. Figure 1-A illustrates a typical frame wall of a barn having vertical or drop siding only, Figure 1-B a wall with sheathing and siding, Figure 2-A a wall with siding and lined on the inside, Figure 2-B the same type of wall filled with commercial insulation. Figure 3-A illustrates the temperature gradients through a single window and 3-B a window and storm sash.

For purposes of illustration only one interior temperature (45° F.) has been used and the temperature gradients calculated for three outdoor temperatures, 20° F., 0° F., and -20° F.; four relative humidity conditions are illustrated by showing the dewpoint temperatures for 90 percent, 80 percent, 70 percent, and 60 percent relative humidity. The water vapor pressures corresponding to these dewpoints are also marked on the respective lines. Saturated vapor pressures corresponding to the temperatures shown are given on the right-hand scale.

When the temperature on the inner face of the wall is above the dewpoint temperature in the room no condensation will take place on that surface, but when it falls below the dewpoint condensation may occur. Note in Figure 1-A that even with a temperature of 20° F. outdoors the temperature of the inner face of the wall practically coincides with the dewpoint temperature for 70 percent relative humidity, and should the relative humidity be above 70 percent condensation could develop. Since wood is permeable to water vapor there will be some outleakage, thus producing a vapor pressure gradient in the barn, and condensation will take place on the inner surface when that surface has a temperature somewhat below the dewpoint temperature within the main body of the barn. If the surface were impermeable to vapor, condensation would occur at that dewpoint temperature. Paint on the exterior would retard the passage of vapor, some kinds of paint more than others and new paint more than old paint. Water below a paint film is liable to cause paint failure.

The inside wall face temperatures on Figure 1-B are somewhat higher than 1-A and this reduces somewhat the tendency for condensation to appear on the inner face of the wall. However, should a vapor-resistant sheathing paper be used between sheathing and siding, vapor passing through the sheathing would, under the stated conditions, condense on the sheathing side of the paper. The temperatures on the inner surface of the wall shown on Figure 2-A are slightly higher than for Figure 1-B. An analysis of this 2-A wall shows that at 70 percent relative humidity inside there would be no condensation on the inner face of the wall when the outside temperature was zero. Assuming that the permeability of the inner lining and outer sheathing were equal it might also be assumed that vapor passing through the inner lining would also pass at the same rate through the outer sheathing. However, conditions are complicated by the differences in vapor pressure on opposite sides of these surfaces and by condensation. Since the rate of movement is a function of the difference in vapor pressure, other factors being equal vapor will move fastest when the greatest difference in pressure exists.

At 45° F. and 70 percent relative humidity within the barn, 0° F. and 100 percent relative humidity outdoors the vapor pressure at the inner surface of the wall lining at point A would be about 0.210 inches of mercury, at the inner surface of the sheathing at point B about 0.073; and outside at point C about 0.038. Since the difference between B and C is 0.035 and between A and B 0.137 and since condensation would occur at B, the vapor movement from A to B would greatly exceed that from B to C. As the temperature at that point is below freezing the condensation would appear as frost or ice.

The same general principle of vapor movement exists in the insulated wall, Figure 2-B. Note that the inner surface of the wall is above the dewpoint for humidities of 90 percent or lower, even in the coldest weather. Of course, the resistance to heat loss offered by the insulation results in a lower temperature at the sheathing line, consequently the sheathing is below the dewpoint at somewhat higher outside temperatures than is the case with uninsulated walls. This fact in turn increases the amount of condensation that may collect, since it materially increases the time during which conditions are favorable for condensation. Insulation does not "draw water" as is sometimes suggested but, because of its efficiency in reducing heat loss, lowers the temperature within the walls and thus sets up the condition that increases the amount that may collect. Some kinds of insulation 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 water vapor. Therefore, they should not be considered a source of protection against condensation. Ice that gathers in cold weather will melt in subsequent mild weather and then the water can back up into the insulation. While certain types of fill insulation are not hygroscopic, water can collect in the interstices.

As a rule, the windows and doors are the first place to show evidence of condensation. Glass is a good conductor of heat, consequently the inner surface of a single pane will invariably be at a lower temperature than the inner surfaces of the walls of the barn. This may be illustrated by comparing the temperature at the glass line, Figure 3-A, with the inner surfaces of the wall types shown. Even with double glazing or storm sash as shown in Figure 3-B, the inner glass surface is at a lower temperature than 1-A. Since glass is not permeable to water vapor there can be no leakage through it, but some vapor will escape through cracks and crevices around the inner sash into the space between the two sash and unless vented to the outside will appear as condensation on the inner surface of the outer glass. Sun shining on a glass surface may melt the accumulated frost, but more frost gathers as soon as the effect of the sun is removed. Repeated wetting and freezing is bad for any type of window.

Conditions that cause condensation in side walls also occur at other places in the structure -- on the ceiling, on the under side of the roof, and even in the ventilators. The hay mow over a cow barn should be dry, but if vapor can leak through the floor and escape through openings into this space condensation will follow unless the moisture can be removed by ventilation.

The movement of water vapor is independent of air movement to the degree that no general circulation is necessary to carry the vapor from its source to the condensing surface. The vapor actually moves by diffusion from sources of higher vapor pressure to zones of lower vapor pressure. Any air movement will, of course, tend to speed up the diffusion and equalization of vapor pressure.

The amount and location of condensation within the walls of stock barns and on the wall surfaces are affected by five factors:

1. Outdoor temperature and humidity.
2. Thermal efficiency of the wall.
3. Indoor temperature and humidity.
4. Resistance of outer wall to vapor movement.
5. Resistance of the inner wall to vapor movement.

To prevent or to minimize condensation it is necessary to bring certain of these factors under some degree of control. As the outdoor temperature and humidity cannot be controlled all possible methods of prevention are limited to the other factors.

Since it is the artificial increase in the humidity in the barn that creates the conditions causing condensation, obviously all possible means of maintaining lower indoor humidities should be considered. Ventilation is the most practical method of lowering the humidity, but because it lowers the temperature as well it has its limitations. Preheating the air used for ventilation would make it possible to control the humidity more or less as desired. It would also have the advantage that a smaller amount of air would serve to keep the humidity down than if cold air were used, and drafts within the stable would be less objectionable.

Wall construction that would permit vapor to pass out readily might be developed; for example, an inner wall of low vapor resistance, preferably insulated so that the inner surface would be above the dewpoint, an outer wall covering and a space between the outer and inner wall ventilated to the outside at top and bottom to allow the vapor to escape. Unfortunately, such construction would be rather expensive, and it has other definite limitations. Obviously it would fail entirely if it were not possible to keep the inside wall surface above the dewpoint of the barn atmosphere.

On the basis of present knowledge, the most positive and least expensive method of preventing condensation within the walls would be the use of vapor resistant barriers at or near the inner face of the wall. Vapor barriers will not, however, prevent condensation upon the indoor surface of a barn wall. The idea of vapor barriers in barn construction is not new. The application of the principle to different types of walls is not generally understood, however, and it may be advantageous to discuss this phase in some detail. Vapor barriers on the inner face of the lining would work particularly well with wall section 2-B, since the inner wall temperature is above the dewpoint for the humidities and temperatures illustrated, and no condensation would occur on the inner face of the vapor barrier. The barrier might even be located on the face of the studs below the inner lining and still be above the dewpoint for humidities below 80 percent. From the standpoint of thermal resistance the studs, however, are not as efficient as fill insulation and the calculated temperature gradients at the studs are indicated by dotted lines. Since the temperature of the inner face of the studs is lower than that of the inner face of the lining adjacent to the insulation, that surface becomes the governing factor. The use of insulation means less heat loss through the walls and this in turn means that more heat is available to use for ventilation. In other words, for a given barn temperature more outside air can be used for ventilation to reduce humidity, where the walls are insulated than where they are not.

Increasing the vapor resistance of the inner surface of wall 1-A would probably have the effect of decreasing the transfusion through the sheathing and increasing the inner surface condensation. Condensation on the inner surface of the sheathing adds a decay hazard. A vapor barrier installed so that condensation is kept away from sheathing, studs, and siding reduces the hazard accordingly, though the dripping water may still be a nuisance. The same principle also applies to wall 1-B. A barrier applied to the inner surface of 2-A would protect the interior of the wall, though it might mean increasing the surface condensation at higher humidities. Condensation on the barrier at that point would be less objectionable than having it collect within the wall.

Complete elimination of condensation on windows is more or less impractical. It may be minimized by maintaining lower humidities and by using storm sash, but even these provisions will not entirely prevent condensation in extremely cold weather. Window frames and sills should be designed to drain rapidly to dispose of any condensation.

The Forest Products Laboratory has been making tests on the vapor resistance of various materials used in building construction and also on many materials that might be used for vapor 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) Light weight asphalt roll roofing material; (2) asphalt impregnated and surface coated sheathing paper, glossy surfaced, weighing 35 to 50 pounds per roll of 500 square feet; (3) laminated paper made of 2 or more sheets of kraft paper cemented together with asphalt, 30-60-30 grade; (4) double faced reflective insulation mounted on paper. None of the materials listed are 100 percent resistant to vapor transmission, but they are intended to reduce the amount entering the wall to the point where any that does enter can escape outward through the outer sheathing without further damage. Painting the inner lining with two or more coats of asphalt or aluminum paint will also be helpful, though these coatings are not as effective as the other barriers mentioned. Furthermore, paint coatings do not offer protection if there are numerous definite cracks or crevices in the surface of the inner sheathing. Such coatings would be more effective on plywood or similar sheet materials having few joints than on standard lumber sheathing.

Barriers as suggested for side walls should also be considered at the ceiling in barns having a hay mow over a stable.

The condensation problem is not limited to dairy barns, but may exist in any tight shelter housing animals or chickens, or other types of farm buildings where some heat and moisture are present during cold weather. The principles of prevention and protection applied to cattle barns will also apply to other types of occupancy. It is quite impossible to cover all of the types and combinations of construction and offer suggestions for each type; therefore, it is the purpose here to discuss principles only and trust that the principles can be applied to the problem peculiar to the related or existing types of construction.

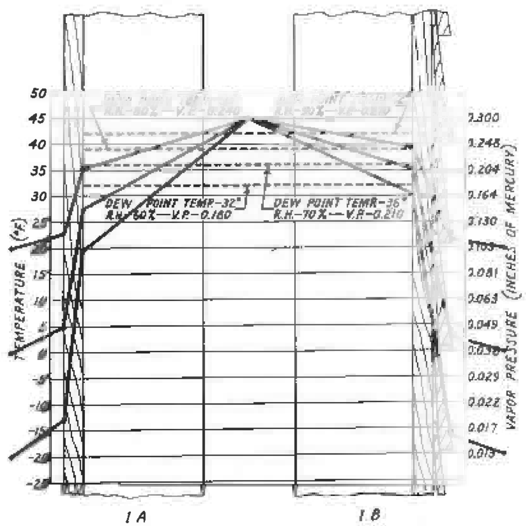

FIG. 1

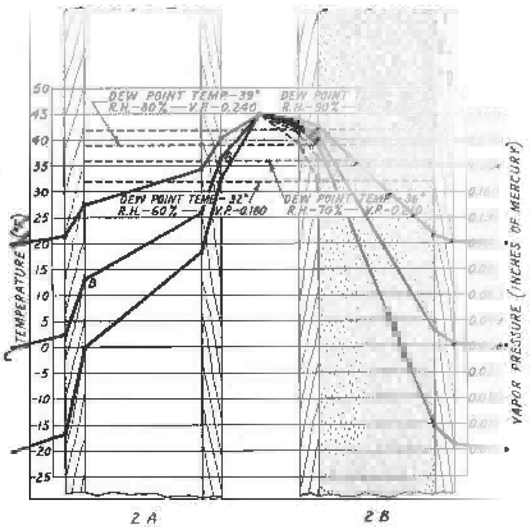

FIG. 2

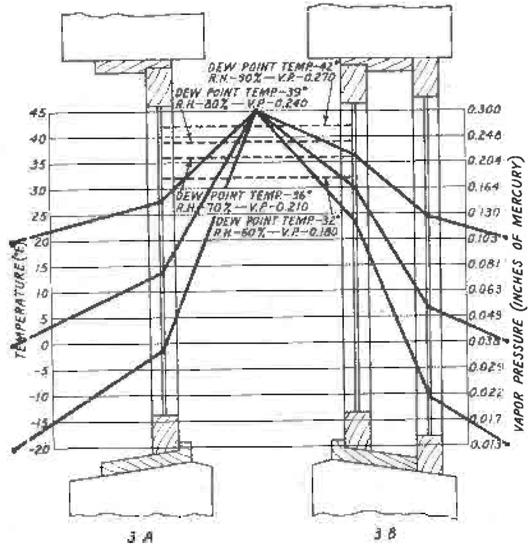

FIG. 3

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