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U. S. Department of Commerce
NATIONAL BUREAU OF STANDARDS
Washington 25, D. C.

Letter
Circular
LC-863

June 6, 1947

CONDENSATION IN BUILDINGS

by

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Introduction

Excessive dampness in buildings or wetness of parts of them can result either from leakage of rain inward from the outside or from condensation of water vapor generated on the inside. Leaks in roofs or walls are not under consideration in this letter circular. The underlying cause of condensation is simple, but the great difference in house design and construction, in climate and in the living habits of families make it impractical to formulate simple remedies applicable to all cases. Obviously, however, architects, builders and home owners should be acquainted with the general principles involved.

Condensation can occur under either summer or winter conditions but the causes and results are different for the two seasons. In winter, water vapor is liberated in houses or buildings by cooking, washing and bathing, sometimes by evaporation from basement floors or earth in crawl spaces, by the use of unvented fuel-burning devices, from potted plants, from clothing dried in the house and, in some cases, by humidifiers used for the purpose. Water vapor is capable of permeating most ordinary building materials such as wall paper, plaster and wood. Hence, high humidity in a house may result in condensation of water not only on the windows but also on or within the exterior walls, the ceiling or the roof. In winter, condensation on window panes is often an indicator of excessive humidity and additional ventilation of the house is a usual remedy. The inner panes of double or storm-windows are warmer than those of single windows under the same conditions so that double windows are less reliable indicators of excessive humidity.

Summer condensation may be prevented by ventilation in conjunction with heat either from sunlight or from some heating device such as a water heater. This is not always adequate so that driers, employing calcium chloride, silica gel or other agents, are often used.

Often a closed, unheated house in a temperate climate becomes damp on the inside. Weather changes contribute to this result. When the basement floor or earth under the house is warmer than the house, convection currents occur. Also, water evaporates from the basement floor and, carried upward by the convection currents, condenses on surfaces or in materials in the upper part of the house. By this means, water is transferred from a basement or a crawl space to the upper part of a house. When the basement is cooler than other parts of the house, the convection currents cease; the air in the house stratifies with the cool air at the bottom and the warm air above.

Water Vapor and Condensation

Condensation is part of the process of distillation whereby a fluid is moved from one place to another by evaporation and subsequent condensation. If some warm water and a cold surface are placed in an enclosure, the water will evaporate, move by diffusion to the cold surface and condense on it either into water again or into ice. The tendency is for the water vapor to move from a warmer to a cooler place. The movement of water vapor is accelerated by air motion which usually exists when there are differences in temperature. If a house is warmer than the outside air, ventilation will tend to dry it. This is the usual cold weather condition. If the house is colder than the outside air, ventilation may make it damp. This occurs sometimes in warm weather when objects or surfaces in the house are for a time colder than the dew-point of the outside air, due to weather changes.

All air, even that in a desert, is admixed with some water vapor and is to that extent humid. Everyone is familar with the "sweat" on a glass containing cold water. This sweat is the same as dew. It represents water vapor or steam condensed from the atmosphere. Its existence proves that the surface of the glass is colder than or "below" the dew-point because, by definition, the "dew point" of air is that temperature of a surface at or below which the surface will condense water from the air.

This water vapor is low-pressure steam. It is invisible; visible "steam" is really mist, consisting of fine droplets. Water vapor, admixed with air, migrates from place to place by diffusion and is conveyed from place to place by the motion of the air. Air movement, termed convection, conveys heat and water vapor from place to place.

When the dew-point temperature is the same as the air temperature, the air is saturated. Needless to say, objects exposed to such air are expected to become damp. Dry air, by definition, contains no water vapor and has no dew-point since no water can be condensed from it. Such air is difficult to produce even in a laboratory. Materials like some of the salts are called "hygroscopic" because they have strong affinities for water and will extract its vapor from air when warmer than the dew-point. Wood and fabrics made of cotton, animal wool or hair, used in house construction and furnishings also have this property. These organic materials sometimes become damp enough to support the growth of mildew or mold when exposed to air somewhat less than saturated. This usually occurs, if at all, in summer or when the house is not heated.

Water vapor can pass through partitions or walls in several ways. If two spaces, one at high and the other at low humidity are separated by a porous substance or membrane, water vapor will

pass through the membrane by diffusion. If the spaces are separated by a hygroscopic material like wood, diffusion will occur but also water vapor will be absorbed on the more humid side, pass through the material and evaporate on the drier side. The tendency will always be, of course, for the water to pass from the more to the less humid side. These facts explain the difficulty of making enclosures, especially buildings, vapor proof. Migration of water vapor would occur even if all workmanship were perfect and cracks and other accidental openings did not exist. However, in ordinary buildings, there are usually cracks due to imperfections in lumber or in workmanship and there are always air currents due to wind pressure, thermal convection or both. Air motion is often more important than diffusion in conveying water vapor within and through the structure of houses and buildings. It is this fact that prevents practical solutions of condensation problems based on a theory of diffusion as precisely as heating problems are solved by a theory of heat transfer and a knowledge of the thermal conductivity of materials.

Some terms in wide use in connection with this subject are as follows:

Absolute Humidity, defined as the amount of water vapor, by weight, mixed with a given quantity of air; often expressed as grains of water per thousand cubic feet of air.

Relative Humidity, defined as the ratio of the water vapor pressure in a space to the water vapor pressure that would exist if the space were staurated; approximately equal to the ratio of the absolute humidity in a space to the absolute humidity that would exist if the space were saturated.

Saturation: Air is said to be saturated with water vapor when, the temperature remaining the same, more water vapor cannot be added to the space containing the air without condensation of a like amount of water.

Dry Bulb Temperature: The temperature of the air indicated by a thermometer with a dry bulb or sensitive element. For precise results the bulb or sensitive element must be shielded from radiation or other extraneous effects.

Wet Bulb Temperature: The temperature indicated by a thermometer with a wetted wick surrounding its bulb. Shielding against radiation is desirable for precision and ventilation with an air stream moving at 15 feet per second or more is essential. The difference between the readings of the dry bulb and the wet bulb thermometer indicates the relative humidity of the air. The sling psychrometer is a simple instrument which gives wet and dry bulb readings with sufficient accuracy for most purposes.

Condensation and Climate

In warm dry climates, condensation is not a problem. Doors and windows are usually open and water vapor generated in the house readily escapes. In warm, damp climates, or seasons, condensation may occur in houses due to weather changes in conjunction with the heat capacity or heat lag in the building parts. This usually happens when warm, humid weather follows several days of cool weather that leaves some objects or surfaces cooler than the dew-point. The usual results are dampness followed by mildew in rugs or hangings and on walls, especially behind furniture or pictures. In cold or temperate regions, whenever the house is kept closed for warmth, the water vapor liberated in it is trapped at the same time. Under this condition, the weather makes little or no difference. Whenever air is warmed, its capacity for carrying water vapor increases. Therefore, air brought in and heated will have a drying effect in the house even though rain is falling and the air outside is practically saturated. When saturated air is warmed, it is no longer saturated, but becomes capable of carrying more water.

Condensation on Windows

A most noticeable consequence of condensation is the formation of frost or ice or of liquid water on the inside of window panes in cold weather. If water, either as liquid or solid, is simply deposited for a time and re-evaporates, no harm is done; but, in bad cases, the water runs down and damages the wall or its finish or any furniture or woodwork in its way. Rotted window frames, sash or sills are a common result. Metal sash are also a problem. Metal is a comparatively good conductor of heat so that such sash is colder, where it is exposed to room air, than wooden sash under the same conditions.

The humidity in houses or buildings is limited in cold weather by condensation especially on the windows and especially if the windows are single glazed. The occurance of excessive condensation on the glass is an indication that ventilation or some other precaution is advisable. For illustration, assume what is impossible, a house with no air leakage and made of non-hygroscopic materials. If water is continually evaporated in such a house, the humidity must inevitably rise until condensation occurs somewhere within it. At a steady state, the condensation rate must equal the evaporation rate. This process of water transfer by distillation would cease if the temperature of all exposed surfaces in the house equalled that of the source of water vapor.

The temperature of single window glass can be fairly well estimated. It depends on the air temperature on the two sides of the glass and on the air motion or wind. For no air motion, the glass temperature will approximate the mean of the indoor and outdoor temperatures. Wind will make the glass somewhat colder. Then the

humidity in the house is such that the dew-point equals the glass temperature, condensation on the window commences. Thus humidity in houses is limited by glass temperature and hence by outdoor temperature and wind. The colder the weather, and the stronger the wind, the lower the inside humidity must be kept if condensation is to be avoided. Humidities which will cause window condensation can be estimated if some assumptions, such as wind velocity, are made. The results of some such calculations are given in Table 1 A.

Outside Temp. °F	1 A Computed Inside Relative Humidity (%) For Window Condensation			1 B Mean of Observed Inside Relative Humidity (%) From BMS 56 Humidifier	
	Single Glazed: No Wind	Single Glazed: Wind 15 MPH	Double Glazed; Wind 15 MPH	Yes	No
40	59	44	73	45	31
30	49	32	66	30	27
20	40	24	50	25	22
10	33	18	51	21*	18*
0	27	13	46		
-10	21	10	40		
-20	19	6	36		

*Extrapolated

Table I - Computed Relative Humidities in Buildings for Incipient Window Condensation. Inside Temperature Assumed: 70°F. Also, Mean of Inside Relative Humidities Observed During Survey of Residence, Reported in NBS BMS Report No. 56. For comparison, Table I B shows the average humidity observed in some homes during a survey described in BMS Report No. 56. (5)

The inside pane of a double or storm window is warmer than a pane of a single window, under the same conditions. Consequently, condensation on the inner pane of a double window occurs only when the humidity is much higher. Therefore, a double window is not so good an indicator of excessive humidity. For this reason it has been suggested that one or more panes be left single, in houses equipped with double or storm windows, as indicators of undesirably high humidities.

Sometimes condensation is observed on the inner surface of the outer pane of a double window. The water vapor which condenses in this location originates within the house and enters the space between the window panes through leaks, usually around the sash.

A remedy is to minimize this leakage as far as is conviently possible and to ventilate the space with outdoor air. This ventilation is sometimes accomplished by boring holes through the outside sash at top and bottom. Good results have been reported with two three-quarter-inch holes per window. If leakage from the inside is prevented, no ventilation is necessary. The difficulty is avoided if factory-made double panes are used which are hermetically sealed at the edges. In some railway passenger cars, renewable capsules containing absorbent material are installed in the space between the window panes to prevent this condensation.

Condensation in Exposed Walls

This subject is complicated because the types of walls in use are numerous and each presents a special problem. In general, vapor barriers on or near the inner surface are desirable. If materials with the properties of vapor barriers are used at or near the outer surface, special precaution may be required to prevent condensation within the wall.

A vapor barrier is a sheet, membrane or diaphragm capable of arresting or of greatly retarding the passage or migration of water vapor. Metal sheet or foil is practically a perfect vapor barrier if the joints between sheets are tight. Other vapor barrier materials, like paper specially treated with bituminous material, are adequate for most practical purposes. The permeability of materials intended for use as vapor barriers is often measured by the standard methods of the Technical Association of the Pulp and Paper Industry or of the American Society for Testing Materials. Most ordinary building materials, including wood, ordinary wall paper, many paints, plaster and masonry are not considered vapor barriers because their permeability is too high.

The impermeability of metal sheet is likely to cause condensation when that material is used as external sheathing on building walls. It constitutes a vapor barrier in the wrong place -- on the outside. When the weather is cold, the metal sheet also will be cold. Water vapor from inside the house can pass through the plaster and other permeable wall components and approach the metal sheet from the inside. When the water vapor concentration is sufficient, condensation will occur, resulting in a deposit of water or of ice on the inner surface of the metal sheet. The water immediately runs downward and that from the ice does so upon melting. Either action can result in wet timber or other material and can promote corrosion in metal or rot in timber. When metal exterior sheathing is used, a practically perfect vapor barrier is required at or near the inner wall surface also. However, this is seldom attained even with a metal interior wall surface. In constructions suggested so far, the cost of making absolutely tight joints, as by soldering or otherwise, is prohibitive. Therefore, various means of ventilating the stud spaces of metal-clad houses with

outdoor air have been suggested and some show promise of success. Work has not yet progressed far enough to permit specifications to be given. However, the usual arrangement includes a couple of inches of insulation adjacent to the inside surfacing material. An air space an inch or so wide is left between the insulation and the external sheathing and the air space is ventilated with outdoor air by means of openings at the top and bottom of each stud space with an area on the order of one or two square inches per opening. Various architectural means have been suggested for concealing the openings and for excluding insects and rodents. The effect of the openings on the heat transfer through the wall probably is small, estimated to be less than 10 percent based on work covered by NBS BMS Report No. 106. Experiments now is progress in various laboratories may throw further light on the subject. Tar or asphalt coated paper can promote wall condensation in the same way as metal sheathing. Such materials should be used, therefore, with proper precautions. Stud space ventilation may prove valuable with other than metal walls. However, experience with it is lacking so that its application rests at present on the judgement of individual designers.

A conventional wooden exterior wall, known as a frame wall, consists of studs, typically 2-in. by 4-in. wooden uprights with lath and plaster on the inside and sheathing boards covered with weather board on the outside. Building paper is usually installed between sheathing and weather board to exclude the wind. This should be a fairly vapor-permeable paper since otherwise it would be a vapor barrier in the wrong place - near the outside of the wall - and would invite condensation in houses carrying high humidity unless precautions are observed similar to those desired for metal sheathing.

Conventional wooden walls are traditionally regarded as trouble-free, so far as condensation is concerned, and work described in BMS 106 indicates that they are so for indoor relative humidities up to 30% and outdoor temperatures down to -10°F. Table I A indicates that condensation can be expected on single glazed windows at less severe conditions. Such windows are often indicators of hazard for such walls because condensation will ordinarily appear on the windows before it occurs in the wall.

Brick veneer walls and stone veneer walls are similar to frame walls except that a layer of brick or of stone is used on the outside of the sheathing instead of weather board. Like frame walls, they contain a space between the studs in which insulation can be installed. The condensation phenomemon is similar for all walls containing such spaces.

Both solid and block masonry walls are in use, some with plaster applied directly to the inside surface and some furred, lathed and plastered. Furring consists of vertical wooden strips, attached to the masonry of the wall. Furring serves to support the

lath and plaster and by this arrangement, an air space is provided between the plaster and the masonry.

Masonry walls with plaster applied directly on the surface are not to be recommended except in arid regions. In temperate climates, such walls often condense water during warm weather when the house is not heated and when the windows are opened for comfort.

Furred masonry walls are usually trouble-free because the masonry is likely to be practically as permeable as the plaster. In winter, water vapor passing through the wallpaper and plaster passes readily through the masonry also, to escape outside. In summer, any condensation occurring on the masonry, due to its heat lag, is hidden from view by the plaster and is so small in quantity that it is readily dissipated without damage to the structure.

Condensation in Roofs and Attic Spaces

Roof coverings, with some exceptions like shingles are practically impervious to the passage of water vapor or of air and an impervious roof covering may create a condensation problem since it constitutes a vapor barrier on the outside of the building where it becomes cold in cold weather and can act as a condenser when water vapor comes in contact with it from below. Water vapor is not prevented from coming in contact with the roof surfacing material by the roofing boards or by plaster used in ceilings since these are pervious and when excessive humidities are not prevented by ventilation or otherwise, condensation may occur in roofs. This condensation not only wets the roof boards but may drip downward and wet the ceiling beneath. These effects are sometimes attributed to leaks in the roof and much effort has undoubtedly been expended uselessly in seeking non-existant leaks. Precautionary measures in the roof construction of some buildings such as offices, churches, etc., may be unnecessary because little water vapor is generated in them. However, the safest roof is one with a space under it which can be ventilated with outdoor air. Any insulation used should be beneath this air space. A roof which is self-ventilating, like a wood shingle roof, may be an exception.

Roofs may be classed as peaked and flat. The peaked roof, the most popular for dwellings, affords an attic space under it. Insulating material may be installed in the floor of the attic if the attic space is not to be used for living quarters. This arrangement is ordinarily safe against condensation provided safe limits of relative humidity are maintained in the house because the natural ventilation or infiltration in attics under peaked roofs is ordinarily sufficient to prevent condensation. However, ventilation of the attic space by means of two or more louvers or their equivalent with an aggregate free area of at least 1/576 of the attic floor area, as suggested by Professor Rowley, is required for new houses by the Federal Housing Administration.

Insulation can be installed in the roof itself when the attic is to be used for living quarters. If this is done, an air space of from one to several inches between the insulation and the roof boards is recommended by some builders. If provided, such a space is worse than useless if it communicates with the inside of the building as through a stud space or pipe shaft. In all cases such spaces should be ventilated with outside air and this ventilation can be provided by leaving spaces between the boards constituting the under side of the exterior overhang. Exact dimensions for such arrangements have not been established. In flat-roofed houses without attics, spaces or cracks between boards from 1/4 to 1/2 inch wide, running the length of the eaves, have been used. Such openings must be protected from the weather and wire netting is usually applied to exclude insects. Wind is relied upon for motive force to cause the ventilation. Roof ventilators are sometimes provided to ventilate spaces under flat roofs. If excessive water vapor is present, condensation under impervious roofs may occur regardless of the presence or absence of insulation.

Condensation in Floors

Condensation in or on ordinary wooden floors is seldom a problem in heated houses in winter. Water vapor generated in a house is always associated with warm air which rises and carries the water vapor with it. This chimney action in the house tends to prevent concentration of water vapor at or near the floor sufficient to cause condensation. Also due to this chimney action, air leakage into the house is likely to be down low, in the absence of wind, while escape of air occurs near the top. Any air brought into the house, whether by wind pressure or chimney action, will have a tendency to dry the house and not to deposit moisture. Condensation may occur near the outer or exposed edges of concrete floors in winter, whether such floors are placed over crawl spaces or on the ground. Concrete is a good heat conductor and floor surfaces near the outside walls of the house may be cooled below the dew-point by the rapid conduction of heat to the outside air. A remedy is to insulate the edge of the concrete slab by means of a strip of insulating material to break the heat path. (4) Specific recommendations cannot be given because standard practices have not been established but the insulations used should be moisture and rot resistant and as an estimate, an inch or more thick.

The results of some experiments at the National Bureau of Standards showed that metal foil insulation, installed under a wooden floor over a crawl space, is not in danger of becoming wet under winter conditions even though higher than normal humidities are maintained above the floor and in the crawl space beneath. The same conclusion is considered to apply to other forms of insulation also. During the warmer seasons and in any but arid climates, condensation is common on floors and its appearance depends on the floor type. (6)

In the spring, the earth under a house is likely to remain cold after the weather is so warm that the heater is turned off and when the house is copiously ventilated by opening windows and doors for comfort. Under this condition, a concrete slab floor on the ground is likely to exhibit condensation, especially under rugs or furniture or in closets where there is some ventilation but not sufficient to promptly warm the floor to some temperature above the dew-point. A rug insulates the floor and prevents the air from heating it, but the rug is pervious to water vapor. Condensation is hence more likely under a rug than on the uncovered floor.

The heat capacity of concrete floors, either on or above grade, in conjunction with weather changes can cause these same symptoms. When cool weather is followed by warm humid weather, the floor tends to remain cool and parts of it may for a time be below the dew-point, with condensation resulting.

Suggested remedies for these conditions include provision of an insulating layer on top of the floor with a covering which is impervious to water vapor, heat applied to the floor as by means of a floor panel heating system, use of dehydrating chemicals to dry the house, etc. Standards of practice have not been set and the solution of the problem rests at present with individual designers or builders.

Sometimes, masonry walls or piers, being good conductors of heat, remain cold with the ground in spring so that wooden joists or other timbers resting on them are cooled sufficiently at the point of contact to gather water from the air and undergo local decay.

Condensation and Crawl Spaces

Consideration of crawl spaces under basementless houses is important chiefly because the earth is a source of water vapor which may be carried by air currents to any of several parts of a house and cause dampness. This is particularly true in the fall when the earth under the house is warmer than the air and , at times, much warmer than many of the house parts. Under this condition, water tends to evaporate from the ground and to be absorbed by house timbers or other wood members. The floor above the crawl space may become damp enough to rot. Sometimes, warm, damp air ascends pipe shafts or spaces in walls and condensation occurs on the cooler under side of the roof.

Remedies for these conditions consist in ventilating the crawl space and treating the ground to decrease evaporation of water from it. The Federal Housing Administration requires ventilation by means of openings of at least one square foot area per 15 linear feet of surrounding wall. Ventilation by means of stacks or ducts extending from the crawl space through the roof has been suggested

but not extensively applied. Ground treatments in crawl spaces have included concrete, bituminous coverings, gravel and roofing felt or tar paper. An effective treatment lessens the need for ventilation. Tar paper, with the edges of adjacent sheets lapping each other several inches but without any sealer or caulking compound, was applied in one large apartment project and is considered adequate. Obviously, openings extending from a crawl space to the underside of the roof, or to another cold surface, should be avoided or stopped up if possible.

Condensation on Pipes and Fixtures

Condensation occurs on water pipes and on bathroom tanks, usually in the spring when the water, passing for a long distance through mains buried in cold earth, is at times below the dew-point temperature of the air. A drip results which is sometimes a nuisance but in most houses this problem is not considered serious enough to require a remedy since the condition does not last long. If necessary, possible remedies are; heating the water or insulating the pipes or tanks. Insulation of the kind used on refrigerator piping is regarded as effective. The insulation should have a vapor resistant outer surface to prevent water penetration to the pipe.

Condensation and Insulation

Water vapor generated within a house in winter spreads in all directions by diffusion assisted by air motion. It passes through ordinary wall paper and plaster and will condense within other building element wherever a surface is below the dew-point. If condensation occurs in a wall, it is likely to be at or near the outside surface since that portion is coldest and an insulated wall is expected to be colder on the outside, and warmer on the inside, than an uninsulated wall. Also, unprotected insulation, although effective as a barrier to heat, is not usually a barrier to water vapor migrating through the wall. For these reasons more precautions against condensation are essential when insulation is used. These precautions take the form of ventilation, minimizing water vapor generation, use of vapor barriers, particularly in new houses, wall ventilation, etc., discussed elsewhere in this letter circular. The effect of insulation in ceilings or roofs is similar. An attic is colder in winter after insulation is installed in its floor and roof boards are colder after insulation is placed under them.

Condensation and Ventilation

Various means have been suggested to prevent excessive humidity in occupied houses in winter, including the use of sorbent materials such as calcium chloride, silica gel, etc., but ventilation probably is most economical and convenient during the season. Condensation can be prevented in any house or building by heat and sufficient ventilation. Ventilation is effective, as previously pointed

out, because warm air can carry much more water vapor, pound for pound, than cold air. Consequently, warm air, leaving a house, conveys more water than is brought in by the cold air which replaces it. Air exists in the form of exhaust grills, ducts, chimneys, etc., or even open windows should be near the sources of water vapor so that the vapor can be expelled without undue loss of heat. An open or partially open window in a kitchen or laundry is more effective than one in a living room or bedroom.

Two reasons why condensation is more likely in present-day houses than in those built some years ago are (1) a great number of small houses are now being built and (2) that, structurally, they are more nearly airtight. This is construed to mean that the water vapor liberation per cubic foot of space is greater in present houses and that the infiltration is considerably less. Infiltration can be called accidental ventilation. It occurs due to leaks in the structure, to flues and fireplaces, and to the opening and closing of doors, etc. Such infiltration probably has prevented condensation and its ensuing troubles in many older houses. At present, the tendency is to reduce infiltration because the public is aware of the fuel saving and increased warmth made possible by so doing. However, the indications are that many houses, especially small, new ones, are inadequately ventilated by natural means and that the time has arrived when ventilators of some kind should be incorporated in house designs. By such means harmful condensation can be prevented both on windows and within the house structure. Hygrometric controllers have been proposed, and may soon be produced, which will start a ventilating fan or, more simply, open a damper in a ventilating duct and prevent excessive humidity. Meantime, householders should inform themselves about this subject and ventilate at least to the extent that water does not condense on and run down the windows. Modern, tightly constructed small houses, fully occupied, equipped with insulation, weatherstripping and/or storm sash require greater precaution against high humidities than more loosely constructed ones.

New Houses and Vapor Barriers

The humidity obviously increases in any building or enclosure in which water is continuously evaporated unless the water vapor is dissapated by ventilation or otherwise. The question, therefore, naturally arises: Why recommend vapor barriers for new houses if ventilation is essential to prevent condensation, whether vapor barriers are used or not? Why not omit vapor barriers and rely solely on ventilation? The answer is that vapor barriers permit maintenance of higher humidity in a house and this is desirable for three reasons. Some persons find low humidities uncomfortable. Glued wooden furniture deteriorates when the humidity is too low and the ventilation required to dispel the water vapor, generated in a house, is less when the humidity is high. This is illustrated by Table 2 which shows that for air entering a house at 32°F, saturated and leaving at 70°F and 30 percent relative humidity, 14,000 cubic feet are necessary to remove one pound of water, in the form of vapor, from the house.

Table 2

	Air In	Air Out				
Temperature	32°F	70°F	70°F	70°F	70°F	70°F
Relative Humidity	Sat.	24%	30%	45%	60%	Sat.
Absolute Humidity (Lbs water/lb air)	0.00379	0.00380	0.00475	0.00712	0.00950	0.01582
Water Vapor removed from House		0.0001	0.0096	0.00333	0.00571	0.01203
Enthalpy (Btu/lb air)	11.758	20.986	22.026	24.636	27.516	34.090
Total Heat removed from House (Btu/lb air)		9.228	10.268	12.878	15.758	22.332
Air necessary to remove 1 lb water vapor from house						
Lbs air/lb water		1,000,000	1042	303	175	83
Cu ft air/lb water		13,450,000	14000	4070	2350	1020

If a house has a volume of 10,000 cubic feet and an infiltration rate of one air change per hour, which is considered typical, the water removal rate is

$$\frac{10,000}{14,000} = 0.714 \text{ lb per hr}$$

Then if the house is equipped with storm windows and vapor barriers and is otherwise arranged for a humidity of 45 percent, the ventilation rate necessary to remove the same amount of water in the form of vapor is

$$4070 \times 0.714 = 2900 \text{ cubic feet per hour}$$

The heat loss due to ventilation in the original case is approximately

$$\frac{10,000}{13.5} \times (70^\circ F - 32^\circ F) \times 0.24 = 6750 \text{ Btu per hour}$$

The heat loss due to the same cause in the second case is

$$\frac{2900}{13.5} \times (70^\circ F - 32^\circ F) = 1960 \text{ Btu per hour}$$

The estimated saving is

$$6750 - 1960 = 4790 \text{ Btu per hour}$$

If the total heat loss of the house is 50,000 Btu per hour for an outdoor temperature of 32°F, the saving amounts to

$$\frac{4790}{50,000} = 9.6 \text{ percent of the total heat loss.}$$

The above figures suggest a water vapor liberation rate on the order of 0.7 pound per hour for a typical house. In some of the older, larger houses, the water evaporated by cooking, washing, etc., is not sufficient to maintain the humidity high enough to suit the occupants and humidifiers are installed to increase it. In small, well insulated houses of the newer type the water vapor liberation is likely to be more than natural ventilation can dispel, and precautions in theform of ventilation and vapor barriers are to be recommended.

Humidity and Health

The term "excessive humidity" has been used in several places in this paper, meaning humidity great enough to cause condensation in a house or building. It would be desirable, if it were possible, to specify humidity with references to health, instead of the durability of the house but, except in the case of hospital patients including premature infants, no universally accepted relation between humidity and health has been established. High humidities have been shown to lower the mortality rate and to improve the condition of such infants and nurseries or incubators can be designed accordingly for them. Normal people inhabit both very dry and very damp regions of the earth and no dependence of health or longevity on humidity has been scientifically established. Occupants of heated houses in cold climates, however, often experience discomfort due to dryness in the nasal passages and throat, especially upon waking, and for this reason many persons desire artificial humidification in their homes. As indicated elsewhere, the indoor humidity in winter is limited by the outside temperature and other factors so that indoor relative humidities of 50 percent or more, which have sometimes been recommended, are usually impracticable when the weather is near freezing or colder. Professor Yaglou of the Harvard School of Public Health, writing for the Journal of the American Medical Association, concludes that extraordinary humidification of houses in winter is not worth while unless the house is specially constructed for the purpose. (2) If physiological studies indicate the desirability, future houses may be disigned for high winter humidities equipped with multiple glazing and nearly impervious vapor barriers on or near the inner surfaces of the exposed walls.

Instruments

For the determination of humidities in buildings, the sling psychrometer is a cheap and effective instrument. (3) It consists of two thermometers mounted on a strip, usually of metal, with a handle at one end such that the thermometers can be whirled in the air. One thermometer bulb is covered with a cloth sock which is wet with water prior to the operation. Whirling continues until successive observations show that the thermometer readings have become steady. This requires a minute or so. The wet bulb thermometer will read lower than the dry bulb (unless the air is saturated) and the greater the difference the lower the humidity. When the wet-and-dry bulb

temperatures are known, the relative humidity dew-point and other properties of the atmosphere can be found from tables or charts published in various handbooks. Unventilated wet and dry bulb thermometers have become largely obsolete on account of their inconsistency. The reading of a wet bulb thermometer is greatly affected by changes in air velocity when the velocity is very low, but for velocities of 15 or 20 feet per second or more, the reading is satisfactorily steady and reproducible. The sling psychrometer is satisfactory for most measurements in air conditioning work and mechanically ventilated psychrometers, particularly suitable for laboratory work, are on the market. In the latter instruments the thermometers are stationary and the air is drawn past their bulbs by means of a fan or blower. The dew-point apparatus and various kinds of hygrometers are used for special purposes.

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* Available from the Superintendent of Documents, Government Printing Office, Washington 25, D.C. at 15 cents per copy.

** May be available for reference in large libraries.