Moisture problems in houses

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Please note

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Winter moisture condensation is probably the most common moisture-related problem that affects houses. In its mildest form, it appears only as harmless surface condensation on windows. In severe cases it causes decay that might affect the structure itself. In between these extremes, it can manifest itself as mildew growth on the interior finish, or as ceiling stains, ceiling leaks or paint peeling.

Moisture is added to room air in a variety of ways. It is also removed in a variety of ways. The balance created between the rate of moisture generation and the rate of moisture removal establishes the equilibrium humidity level (or relative humidity) in a house, and consequently the potential for future problems.

This Digest examines the causes of condensation problems and ways of reducing or eliminating them.

Sources of Moisture

Moisture can be added intentionally to room air through the use of humidifiers, or unintentionally through normal living activities. It is also added as ground moisture that migrates through the foundation walls and basement or crawl space floors from the surrounding soil.

It is estimated that an average family of 4 generates 7 to 12 litres of water on an average day.[1, 2] This could increase to over 23 litres on wash days. Table 1 shows typical amounts of moisture generated by normal living activities.[1]

Table 1. Moisture Generation In Houses

Sources of Moisture	Quantity, L
Floor mopping 7.4 m²	1.09
Clothes drying* (unvented)	11.97
Clothes washing* (unvented)	1.96
Cooking (unvented)* (If gas, add 1.24L)	0.92
Bathing-	
Shower	0.23
Tub	0.05
Dishwashing*	0.45
Human Contribution (per H)(average)	0.18

House Plants (per H)	0.02

*Based on a family of 4

Exposed earth floors in crawl spaces or basements can produce as much as 45 litres of water a day if the ground is wet. Even exposed rock can release substantial quantities of moisture. Earth floors should therefore always have a ground cover (usually 0.10 or 0.15 mm polyethylene) to reduce the amount of moisture entering the house. Hygroscopic materials, such as wood, will also contribute moisture. Wood absorbs increasing amounts of moisture from the air as the relative humidity increases. In regions with elevated summer and fall humidities, it could absorb an additional 4 to 5 percent of its weight in moisture. This moisture will be released during the heating season, when indoor humidities are lower.[3] Assuming an average moisture increase of 4%, the floor assembly and partition framing of a typical house* will contribute approximately 100 additional litres of water during the heating season. This is only a portion of the total water contributed by all materials, however, as they adjust to the drier indoor humidities.

Moisture added during construction by concrete, plaster, and unseasoned wood will also be released during the initial heating season. Therefore, moisture problems tend to be most severe the first year after construction.

Moisture Removal

Moisture can be removed in three basic ways: by diffusion through the building envelope, by mechanical dehumidification and by the replacement of interior air with exterior air.

Moisture removal by diffusion occurs as the moisture migrates through the enclosing materials in the direction of lower water vapour pressure towards the exterior. This accounts for a relatively small proportion of the total moisture.[2] For instance, in a house with a polyethylene vapour barrier, diffusion accounts for less than 5 percent of the total moisture removal.

Mechanical dehumidifiers remove moisture from room air by blowing it through a series of cooling coils. Water is condensed on the coils where it is collected and removed.

Dehumidifiers are normally designed for optimum efficiency at 27°C air temperature and 60% relative humidity (RH). At normal room temperatures and humidity levels below 50%, their efficiency drops markedly.[1] Since relative humidities in excess of 40% or so can cause serious condensation during cold weather, dehumidifiers are not very practical in winter. They are more effective when used in the summer to reduce basement humidity levels, which can be considerably higher than 50% RH.

The greatest proportion of moisture is removed from houses by the replacement of inside air with outside air. When cold outside air is introduced into a house and heated, its relative humidity is reduced, and it can absorb additional moisture. (Outside air at -30°C and 100% RH when heated to 20°C, for example, will have an RH of less than 2%.) The constant replacement of inside air with outside air carries away moisture; the higher the air replacement rate, the lower the humidity level.

The air exchange routes may be as direct and obvious as ducts, flues, or open doors and windows. They may also be indirect, through the fabric of the building: at the junction between foundation and sill plate, or through the numerous cracks and openings that exist in seemingly solid walls and ceilings that enclose the heated space.

Moist air that escapes directly, without passing through stud spaces or roof spaces, does not normally create problems. When the exfiltration route does pass through these spaces, however, condensation can occur within them giving rise to a variety of potential problems.

Outside and inside air are exchanged due to the pressure differences between the two, created by mechanical equipment (such as exhaust fans or heating equipment), wind pressures, and by what is referred to as the "stack effect" of room air.

The buoyancy of warm air creates a pressure difference between outside and inside air in the same way that hot air creates a draft in a chimney stack or flue. This "stack effect" acts simultaneously with pressure caused by wind action, sometimes complementing it, and sometimes subtracting from it. In a flueless house, the stack effect will induce air out of the upper portions and into the lower portions of the house. In a house with a flue, however, the flue creates an additional demand for air through its own stack effect, which lowers the internal air pressure: the greater the temperature difference between the flue gas and the outside air, the greater the draft. If this draft is sufficiently high, the entire house may be at a lower pressure than the outside air and all air leakage through the building envelope from stack action will be inward.

Flues promote increased air changes as the outdoor temperature decreases. As the weather gets colder, the periods of furnace operation will be longer. In addition, the greater difference in temperature between the flue gas and outside air in colder weather increases the flue draft and, consequently, the rate of air infiltration. Tests indicate that when the furnace is operating, the air flow up the flue may account for about half of the total air change.[4] The effect of a flue can be partially imitated by an insulated ventilating duct, extending from the basement or living area to above the roof level. Preliminary tests indicate that these ducts can reduce humidity levels by inducing additional infiltration. The duct should be insulated where it passes through unheated space to reduce the possibility of condensation within the duct. The insulation will also help keep the duct air warm, thereby maintaining a draft for the upward movement of air.

Vents installed to exhaust air from clothes dryers, kitchens and bathrooms, like chimney flues, tend to depressurize houses and induce air leakage inward rather than outward. These vents remove air at the source of moisture generation, before it infiltrates concealed wall and roof spaces, thus reducing the possibility of hidden condensation.

Mechanical ventilation may also be provided by a duct to convey outside air to the cold air return side of the furnace.[5] This method has been used extensively for many years to reduce winter condensation problems. When the furnace blower operates, a suction is created in the cold air plenum, drawing additional outside air into the house. This has advantages and disadvantages. It pressurizes the house slightly, encouraging air leakage out through the wall and roof spaces where it could lead to condensation problems. But since additional air flow is induced up the flue as well, the moisture carried into the concealed spaces is probably not very significant. Pressurization of the inside air, on the other hand, can be used to control the entry of unwanted gases emanating from the soil or certain building materials.

In furnaces with low flue gas temperatures, introducing outside air into the return air plenum could cause condensation of the flue gas in the furnace heat exchanger. Unless the heat exchanger is designed to resist corrosion, the acidic condensate might damage it in time and flue gas could escape into the air distribution system. If this ventilation system is used, therefore, the furnace should be periodically examined for evidence of deterioration.

Mechanical ventilation systems incorporating heat exchangers may also be used to reduce condensation problems where energy conservation considerations warrant their use. However, the potential energy saving benefits of these systems cannot be attained unless the house is substantially air tight.

Surface Condensation

If moisture is generated faster than it can be removed, the relative humidity will rise until condensation occurs. Condensation will occur on a surface when its temperature falls below the saturation temperature (or dew point) of the air adjacent to it. The inside surface temperature of an exterior wall, for example, will depend on the indoor and outdoor air temperatures and on the amount of thermal resistance between the surface and the exterior. The air's ability to hold moisture decreases as its temperature is lowered. Air adjacent to a colder surface loses its capacity to store moisture as it cools, and eventually condensation occurs. Lower humidity levels are usually required in colder weather to reduce this risk. Because of their lower surface temperatures, windows are usually the first surfaces on which condensation is noticed. For that reason they are often used as an indicator of excessive humidity. (Minor condensation can occur without excessive humidities however and can be ignored if it is not causing problems.)

Excessive humidity also causes condensation within closets and kitchen cabinets, because these surfaces are shielded from the heated room air and are cooler than unshielded surfaces. The corners at the junction of walls and ceiling are also prime locations for condensation problems. The presence of framing and the influx of cold air around the perimeter of the ceiling from the roof vents can lead to lower surface temperatures at these locations. Improperly applied insulation can also be a factor. Care must be taken to ensure uniform and effective coverage of the entire insulated area.

The calculated humidity levels at which condensation will occur on window surfaces are shown in Figure 1. These are only approximations since a number of factors can affect window surface temperatures. For example, the perimeter is colder than the centre of the glass and will therefore show condensation earlier.

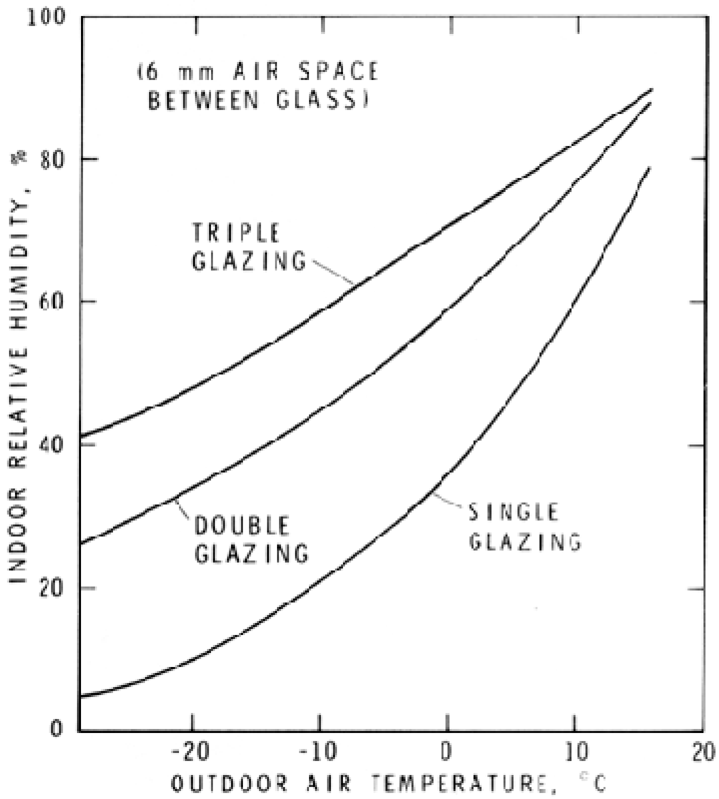

Figure 1. Relative humidities at which surface condensation will occur

The equilibrium humidity level that is eventually reached will depend not only on the rate of moisture generation, but on its rate of removal as well. Figure 2 shows the humidity levels that would be reached in a typical house* for different rates of moisture generation and air change. Curve 1 shows the effect of heating outdoor air at 80% RH to indoor temperature without adding moisture. Curves 2 to 5 illustrate the equilibrium relative humidities for two rates of moisture generation (11.5 litres per day to represent average days, 23 litres per day to represent wash days) and two rates of air change (0.5 and 0.25 air changes per hour to represent relatively tight houses with and without flues), again assuming 80% outdoor RH. (Doubling the rate of moisture generation has the same effect on the relative humidity as halving the air change rate, therefore curves 1 and 4 coincide.) Since actual moisture generation and air change rates vary, these curves are provided only to illustrate the relationship between air change, moisture generation and outdoor temperature. Observed humidity levels from a national study undertaken a number of years ago, are also shown for comparison.[6] The effect of air change rates and moisture generation on the possibility of condensation may be assessed by superimposing Figure 1 on Figure 2.

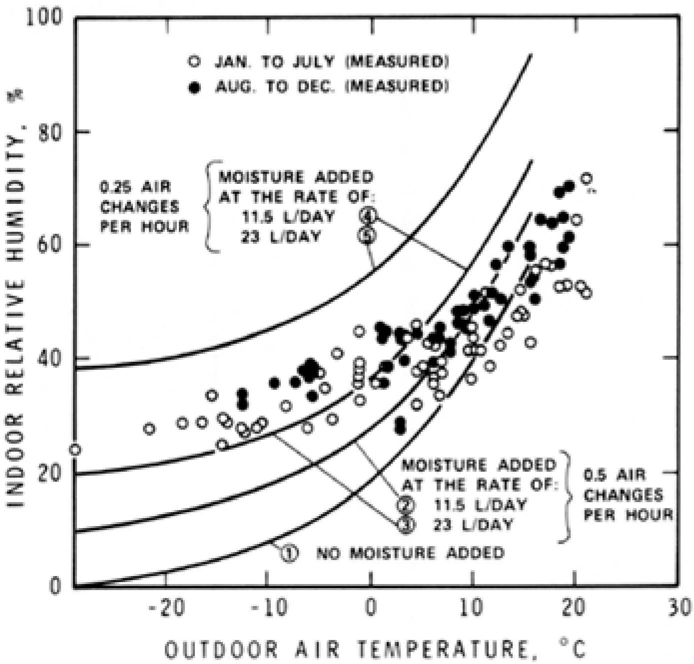

Figure 2. Equilibrium humidities for constant rates of moisture generation and ventilation (calculated for outdoor air at 80% RH)

Condensation control through ventilation becomes more difficult as outdoor air at an elevated humidity level approaches the temperature of indoor air. As the outdoor temperature increases, the inside glass surface temperature increases. Thus higher humidity levels can be maintained without causing condensation. As the outdoor temperature increases, however, outside air at a constant relative humidity is able to absorb less and less moisture when it is heated to room temperature. At some point, this diminishing capacity to absorb additional moisture becomes the overriding factor. When the temperature rises above this point, the ventilating air is able to absorb less and less moisture before window condensation occurs. This effect is shown in Figure 3.

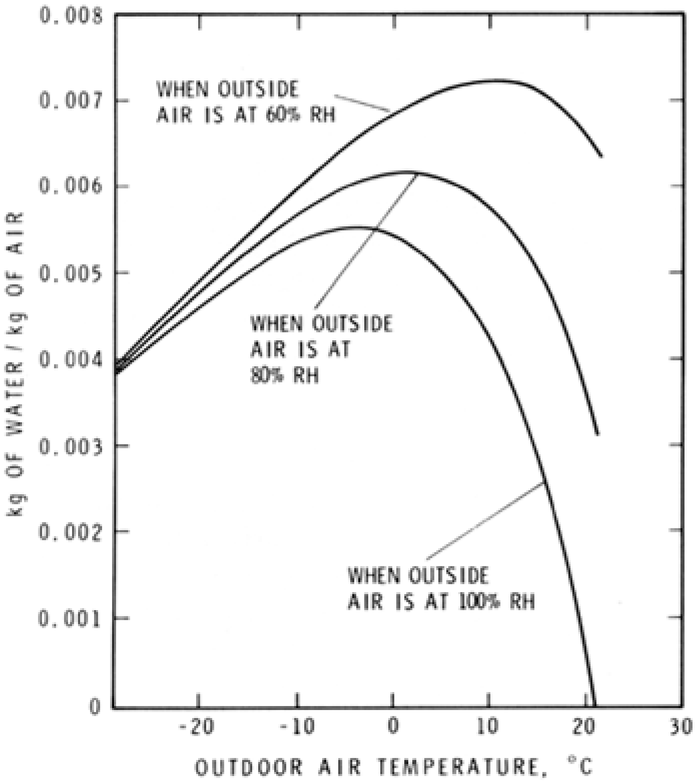

Figure 3. Maximum amount of water that can be added to air before condensation occurs on doubled glazing

Outdoor air at a relative humidity of 100%, for example, will be least likely to cause condensation when the outdoor temperature is about -4°C. Above (or below) this optimum value the condensation risk is increased. Above this value, the outside air will quickly lose its ability to absorb additional moisture, making condensation control through ventilation very difficult. This explains why the greatest number of condensation problems are reported in the fall, at the beginning of the heating season. Also the hygroscopic materials in the house usually dry out at this time, adding to the problem. During these periods, dehumidifiers may be more effective in controlling indoor condensation than ventilation.

Hidden Condensation

All houses undoubtedly experience some condensation within wall and roof spaces during cold weather. This condensation does not generally cause problems however since it is usually dissipated before decay can start.

The optimum conditions for decay occur when the moisture content of the wood is at or above its fibre saturation point (around 30%) and the temperature is from 18° to 35°C. At temperatures above 38°C decay organisms are destroyed. Below 18°C their growth is slowed, and around 0°C, it practically ceases. Wood can therefore be wet for prolonged periods without decay, provided that the temperature is near 0°C or over 38°C. If the moisture content is maintained below 20% decay will not occur, regardless of the temperature.

As windows and doors are made more air tight and flues are blocked off or eliminated, a higher percentage of the total moisture will be expelled by air leakage through the exterior wall and ceiling spaces.

Contrary to what one may expect, condensation does not occur initially within the insulation, even though the temperature may be below the dew point of the air. It collects on the first solid surface that is below dew point temperature, usually the wall or roof sheathing. If the condensing surface's temperature is below freezing, the condensation will be in the form of frost or ice. When condensation progresses to the stage that the insulation becomes wet, its thermal resistance decreases, promoting surface condensation on the room side as well.

Holes cut for electrical boxes in exterior walls and ceilings create obvious opportunities for air leakage into concealed spaces when there is a positive internal air pressure. There are many other less obvious entry points as well. Holes drilled for electrical wiring are usually oversized to facilitate wire installation. They not only connect adjacent stud and joist spaces, but when drilled through top and bottom wall plates, they connect the basement and the attic with the walls adjacent to them. This creates a path for moist room air. Plumbing installations have the same effect. Less obvious still are the leakage paths created where floors or partitions intersect exterior walls, where partitions intersect ceilings, or where bathtubs are adjacent to exterior walls.

Leakage paths are also created when the framing dries and shrinks. Since the finish is held in place by fasteners that do not shrink, spaces are created between the finish and the framing as the lumber dries.

Exhaust ducts that run through concealed spaces and operate under positive pressure can deposit large quantities of moisture in attic and stud spaces if their seams and joints are not air tight. Vapour barriers located between the wall finish and the insulation can reduce air leakage into concealed spaces, but their effectiveness depends on the care with which they are installed and the degree to which they can be made air tight, without openings or discontinuities.

Since excess condensation can usually drain from all spaces and escape, condensation problems in walls are not as frequent or as severe as those in roofs. The water that does not drain away must eventually be dissipated by diffusion through the enclosing construction or by air leakage into and out of the concealed space. If the enclosing construction is vapour resistant and tightly constructed, excess moisture may be retained long enough for decay to develop. This possibility is increased in areas where the prevailing outdoor humidity levels are high for prolonged periods during the spring. In some areas, the combined effects of large families, flueless houses, vapour resistant sheathing materials and poor spring drying conditions can increase the risk of serious wall condensation problems to the point where remedial measures such as mechanical ventilation must be considered.

The majority of serious roof condensation problems occur with flat roofs rather than roofs with attic spaces. In houses with attic spaces, the moisture is diffused over a large surface before it condenses. In flat roofs the condensing surface of the sheathing is relatively close to air leakage sources and the moisture therefore concentrates near the air leak. As the weather warms, the accumulated frost and ice melts and falls into the insulation below. The concentration of moisture may be sufficient to cause wet spots on the ceiling. Flat roofs are also difficult to ventilate effectively because of the limited airspace between the insulation and sheathing. This can prolong the drying period when the weather warms thus increasing the risk of decay.

To reduce the build-up of winter condensation and to speed up the drying during the spring, at least twice the vent area necessary for roofs with attic spaces is specified for flat roofs. (Usually $^{1}/150$ of the ceiling area). Serious roof condensation problems will not be corrected by increased roof venting alone. Leakage paths must be sealed, and where necessary increased room ventilation provided.

The greater the air space between the insulation and the roof sheathing, the more freely outdoor air can move through this space. A clearance of 75 mm or more between the insulation and the roof sheathing is normally specified.

Summary

The rate of moisture production and the rate of its removal establishes the resulting levels of humidity in a house. Living activities, humidification, ground moisture and the house itself, all contribute to the moisture load. Most of this is removed by exchanging inside air with outside air, and only a small portion is removed by vapour diffusion through the enclosing envelope.

Most houses experience some degree of condensation, but only a relatively small percentage will develop serious problems because of it. Attention to detail is required during construction to ensure that there will be as few leaks as possible that will permit room air to enter concealed spaces. The provision of additional ventilation can also be used to control condensation, particularly in houses without the benefit of a flue.

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* Where a "typical house" is referred to, it is assumed to be a one storey bungalows with a full basement and a ground floor area of 111 m² (1200 sq. ft.).