Appendix C: Moisture, Mold and Mildew

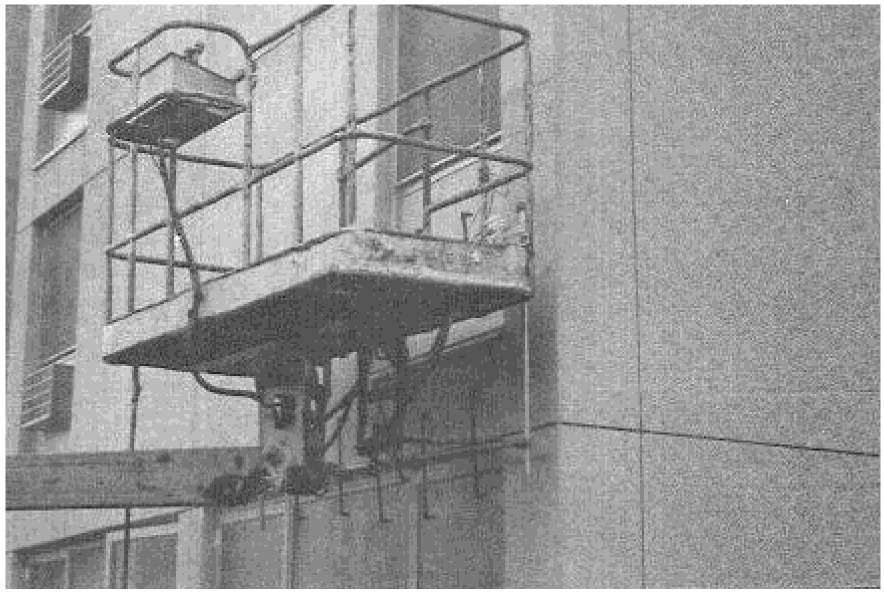
Molds and mildew are fungi that grow on the surfaces of objects, within pores, and in deteriorated materials. They can cause discoloration and odor problems, deteriorate building materials, and lead to allergic reactions in susceptible individuals, as well as other health problems.

The following conditions are necessary for mold growth to occur on surfaces:

- temperature range above 40°F and below 100°F
- mold spores
- nutrient base (most surfaces contain nutrients)
- moisture

Human comfort constraints limit the use of temperature control. Spores are almost always present in outdoor and indoor air, and almost all commonly used construction materials and furnishings can provide nutrients to support mold growth. Dirt on surfaces provides additional nutrients. Cleaning and disinfecting with non-polluting cleaners and antimicrobial agents provides protection against mold growth. Other sections of this document have discussed the importance of building maintenance and proper sanitation in preventing IAQ problems. However, it is virtually impossible to eliminate all nutrients. Moisture control is thus an important strategy for reducing mold growth.

Mold growth does not require the presence of standing water; it can occur when high relative humidity or the hygroscopic properties (the tendency to absorb and retain moisture) of building surfaces allow sufficient moisture to accumulate. Relative humidity and the factors that govern it are often misunderstood. This appendix is intended to give building managers an understanding of the factors that govern relative humidity, and to describe common moisture problems and their solutions.

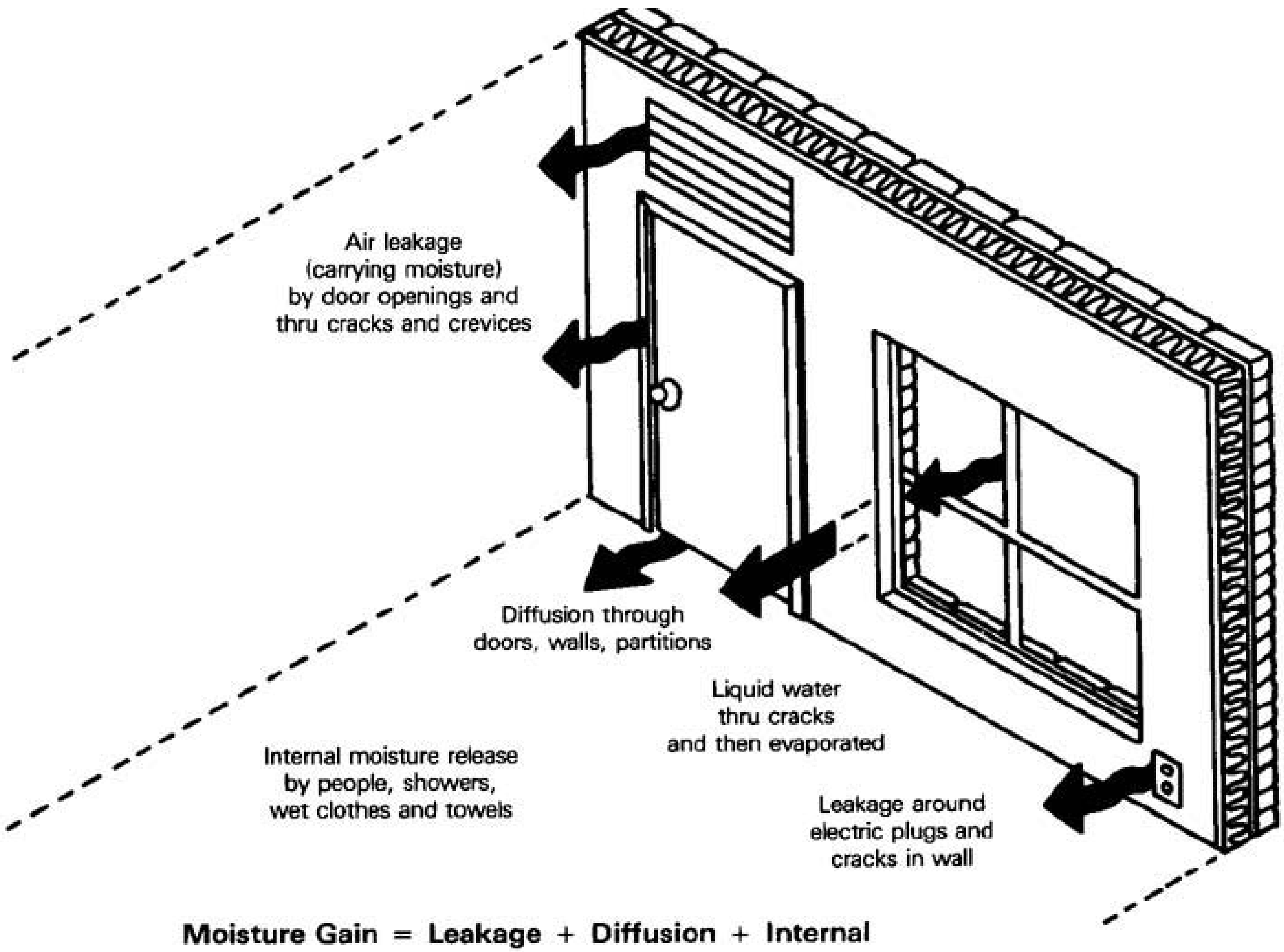


There were complaints of visible water damage and musty odors in this senior citizen housing complex. Investigators confirmed that the problem was rain entry by using an array of hoses to spray the walls with water, while operating the building under negative pressure. The test showed that rain was entering at the joints of the exterior cladding, rather than at cracks around windows.

BACKGROUND ON RELATIVE HUMIDITY, VAPOR PRESSURE, AND CONDENSATION

Water enters buildings both as a liquid and as a gas (water vapor). Water, in its liquid form, is introduced intentionally in bathrooms, kitchens, and laundries and accidentally by way of leaks and spills. Some of that water evaporates and joins the water vapor that is exhaled by building occupants as they breathe or that is introduced by humidifiers. Water vapor also moves in and out of the building as part of the air that is mechanically introduced or that infiltrates and exfiltrates through openings in the building shell. A

FIGURE C-1: Moisture Gain in a Building



Courtesy of Dean Wallace Shakun, Clayton State College, Morrow, GA

lesser amount of water vapor diffuses into and out of the building through the building materials themselves. Figure C-1 illustrates locations of moisture entry.

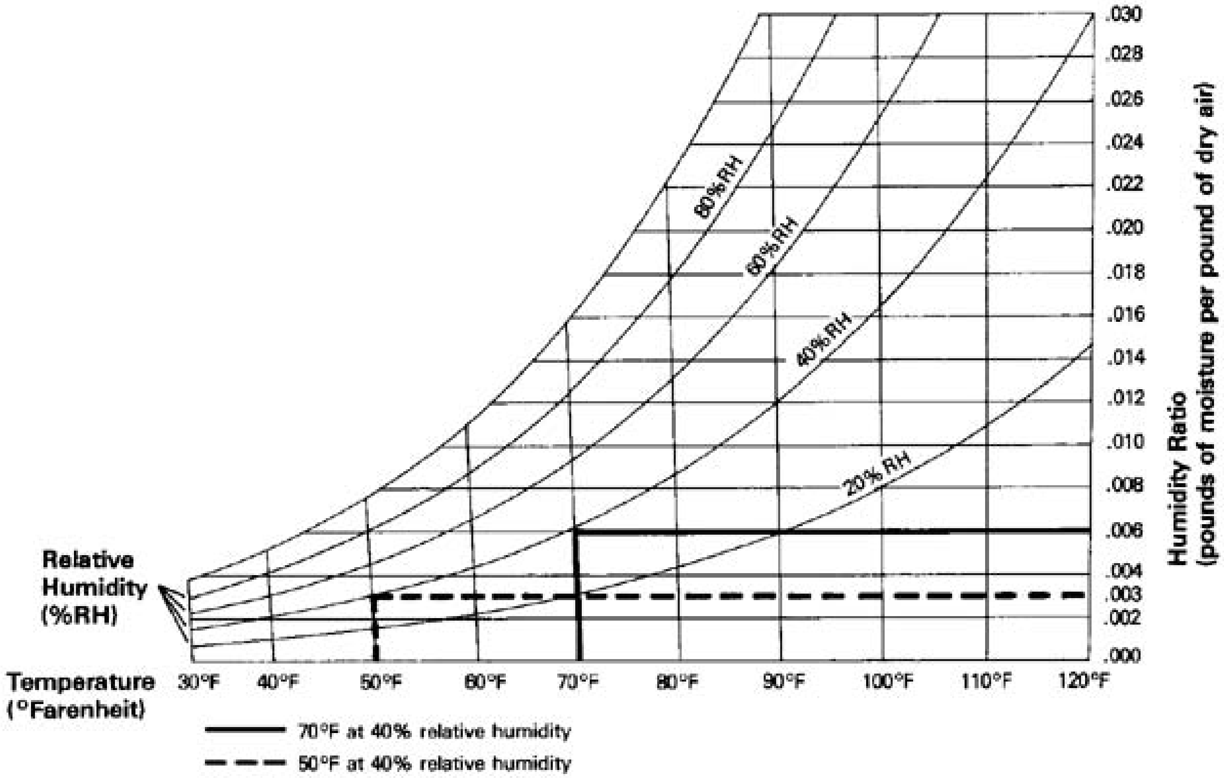
The ability of air to hold water vapor decreases as the air temperature is lowered. If a unit of air contains half of the water vapor it can hold, it is said to be at 50% relative humidity (RH). As the air cools, the relative humidity increases. If the air contains all of the water vapor it can hold, it is at 100% RH, and the water vapor condenses, changing from a gas to a liquid. It is possible to reach 100% RH without changing the amount of water vapor in the air (its "vapor pressure" or "absolute humidity"); All that is required is for the air temperature to drop to the "dew point."

Relative humidity and temperature often vary within a room, while the absolute humidity in the room air can usually be assumed to be uniform. Therefore, if one side of the room is warm and the other side cool, the cool side of the room has a higher RH than the warm side.

The highest RH in a room is always next to the coldest surface. This is referred as the "first condensing surface," as it will

FIGURE C-2: Relationship of Temperature, Relative Humidity, and Moisture in the Air

A relative humidity reading taken in a room will only give an accurate indication of the actual amount of moisture present if a temperature reading is taken at the same time. The chart below shows that air at 70°F and 40% RH contains approximately 0.006 pounds of moisture per pound of dry air (as indicated by the bold line), while air that is at 50°F and 40% RH contains approximately 0.003 pounds of moisture per pound of dry air (as indicated by the dashed line). Although both are at 40% RH, the 70°F air contains roughly twice as much moisture as the 50°F air.

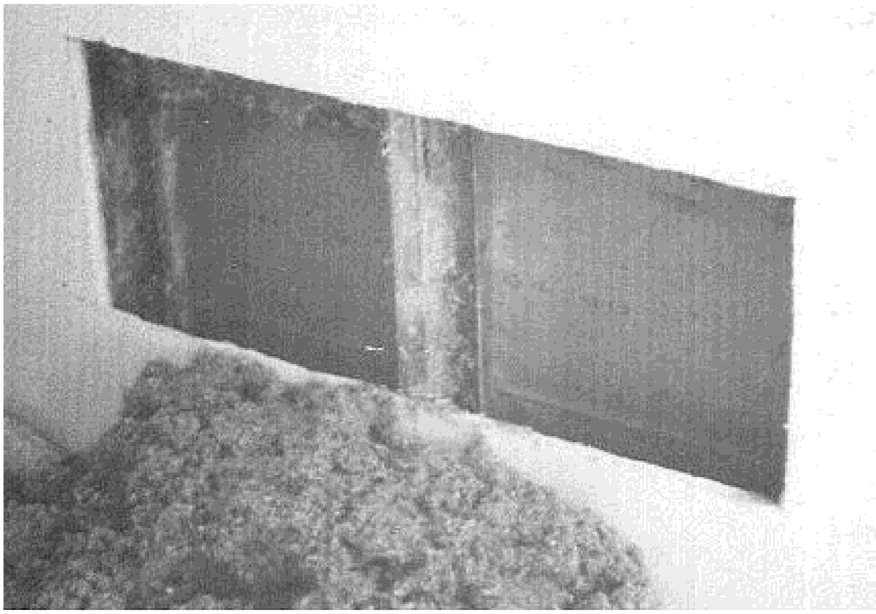


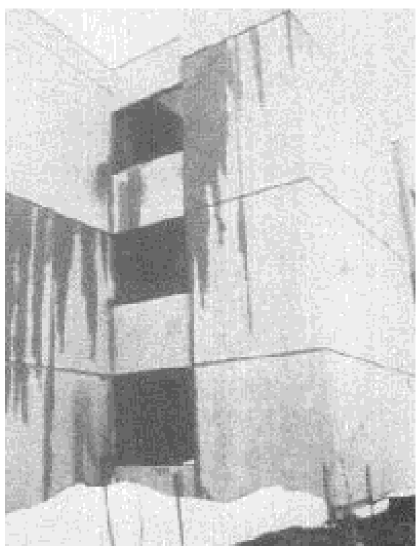
SOURCE: Adapted from Psychometric Chart from ASHRAE Fundamentals, 1981

be the location where condensation first occurs, if the relative humidity at the surface reaches 100%. It is important to understand this when trying to understand why mold is growing on one patch of wall or only along the wall-ceiling joint. It is likely that the surface of the wall is cooler than the room air because there is a void in the insulation or because wind is blowing through cracks in the exterior of the building.

TAKING STEPS TO REDUCE MOISTURE

Mold and mildew growth can be reduced where relative humidities near surfaces can be maintained below the dew point. This can be accomplished by reducing the moisture content (vapor pressure) of the air, increasing air movement at the surface, or increasing the air temperature (either the general space temperature or the temperature at building surfaces).





Above: *In this building, mold and mildew spots appeared on drywall joints on the interior walls. When the wall was cut open, mold growth was visible in the wall cavity and the structural steel showed corrosion. The problem was caused by construction moisture trapped between the interior finish and the exterior sheathing. The solution was to modify the exterior wall so that moisture could vent to the outdoors.* ***Below:*** *This is visual evidence of air movement through the building shell. The water vapor in the warm, humid indoor air has condensed and frozen on the exterior wall.*

Either surface temperature or vapor pressure can be the dominant factor in causing a mold problem. A surface temperature-related mold problem may not respond very well to increasing ventilation, whereas a vapor pressure-related mold problem may not respond well to increasing temperatures. Understanding which factor dominates will help in selecting an effective control strategy.

Consider an old, leaky, poorly insulated building. It is in a heating climate and shows evidence of mold and mildew. Since the building is leaky, its high natural air exchange rate dilutes interior airborne moisture levels, maintaining a low absolute humidity during the heating season. Providing mechanical ventilation in this building in an attempt to control interior mold and mildew probably will not be effective in this case. Increasing surface temperatures by insulating the exterior walls, and thereby reducing relative humidities next to the wall surfaces, would be a better strategy to control mold and mildew.

Reduction of **surface temperature-dominated mold and mildew** is best accomplished by increasing the surface temperature through either or both of the following approaches:

- Increase the temperature of the air near room surfaces either by raising the thermostat setting or by improving air circulation so that supply air is more effective at heating the room surface.
- Decrease the heat loss from room surfaces either by adding insulation or by closing cracks in the exterior wall to prevent wind-washing (air that enters a wall at one exterior location and exits another exterior location without penetrating into the building).

Vapor pressure-dominated mold and mildew can be reduced by one or more of the following strategies:

- source control (e.g., direct venting of moisture-generating activities such as showers) to the exterior
- dilution of moisture-laden indoor air with outdoor air that is at a lower absolute humidity
- dehumidification

Note that dilution is only useful as a control strategy during heating periods, when cold outdoor air tends to contain less moisture. During cooling periods, outdoor air often contains as much moisture as indoor air.

IDENTIFYING AND CORRECTING COMMON PROBLEMS FROM MOLD AND MILDEW

Exterior Corners

Exterior corners are common locations for mold and mildew growth in heating climates, and in poorly insulated buildings in cooling climates. They tend to be closer to the outdoor temperature than other parts of the building surface for one or more of the following reasons:

- poor air circulation (interior)
- wind-washing (exterior)
- low insulation levels
- greater surface area of heat loss

Sometimes mold and mildew growth can be reduced by removing obstructions to airflow (e.g., rearranging furniture). Buildings with forced air heating systems and/or room ceiling fans tend to have fewer mold and mildew problems than buildings with less air movement, other factors being equal.

"Set Back" Thermostats

Set back thermostats are commonly used to reduce energy consumption during the heating season. Mold and mildew growth can occur when building temperatures are lowered during unoccupied periods. (Maintaining a room at too low a temperature can have the same effect as a set back thermostat.) Mold and mildew can often be controlled in heating climate locations by increasing interior temperatures during heating periods. Unfortunately, this also increases energy consumption and reduces relative humidity in the breathing zone, which can create discomfort.

Air Conditioned Spaces

The problems of mold and mildew can be as extensive in cooling climates as in heating climates. The same principles apply: either surfaces are too cold, moisture levels are too high, or both.

A common example of mold growth in cooling climates can be found in rooms where conditioned "cold" air blows against the interior surface of an exterior wall. This condition, which may be due to poor duct design, diffuser location, or diffuser performance, creates a cold spot at the interior finish surfaces. A mold problem can occur within the wall cavity as outdoor air comes in contact with the cavity side of the cooled interior surface. It is a particular problem in rooms decorated with low

HOW TO IDENTIFY THE CAUSE OF A MOLD AND MILDEW PROBLEM

Mold and mildew are commonly found on the exterior wall surfaces of corner rooms in heating climate locations. An exposed corner room is likely to be significantly colder than adjoining rooms, so that it has a higher relative humidity (RH) than other rooms at the same water vapor pressure. If mold and mildew growth are found in a corner room, then relative humidities next to the room surfaces are above 70%. However, is the RH above 70% at the surfaces because the room is too cold or because there is too much moisture present (high water vapor pressure)?

The amount of moisture in the room can be estimated by measuring both temperature and RH at the same location and at the same time. Suppose there are two cases. In the first case, assume that the RH is 30% and the temperature is 70°F in the middle of the room. The low RH at that temperature indicates that the water vapor pressure (or absolute humidity) is low. The high surface RH is probably due to room surfaces that are "too cold." Temperature is the dominating factor, and control strategies should involve increasing the temperature at cold room surfaces.

In the second case, assume that the RH is 50% and the temperature is 70°F in the middle of the room. The higher RH at that temperature indicates that the water vapor pressure is high and there is a relatively large amount of moisture in the air. The high surface RH is probably due to air that is "too moist." Humidity is the dominating factor, and control strategies should involve decreasing the moisture content of the indoor air.

maintenance interior finishes (e.g., impermeable wall coverings such as vinyl wallpaper) which can trap moisture between the interior finish and the gypsum board. Mold growth can be rampant when these interior finishes are coupled with cold spots and exterior moisture.

Possible solutions for this problem include:

- preventing hot, humid exterior air from contacting the cold interior finish (i.e., controlling the vapor pressure at the surface)
- eliminating the cold spots (i.e., elevating the temperature of the surface) by relocating ducts and diffusers
- ensuring that vapor barriers, facing sealants, and insulation are properly specified, installed, and maintained
- increasing the room temperature to avoid overcooling

In this case, increasing temperature decreases energy consumption, though it could cause comfort problems.

Thermal Bridges

Localized cooling of surfaces commonly occurs as a result of "thermal bridges," elements of the building structure that are highly conductive of heat (e.g., steel studs in exterior frame walls, uninsulated window lintels, and the edges of concrete floor slabs). Dust particles sometimes mark the locations of thermal bridges, because dust tends to adhere to cold spots.

The use of insulating sheathings significantly reduces the impact of thermal bridges in building envelopes.

Windows

In winter, windows are typically the coldest surfaces in a room. The interior surface of a window is often the first condensing surface in a room.

Condensation on window surfaces has historically been controlled by using storm windows or "insulated glass" (e.g., double-glazed windows or selective surface gas-filled windows) to raise interior surface temperatures. The advent of higher performance glazing systems has led to a greater incidence of moisture problems in heating climate building enclosures, because the buildings can now be operated at higher interior vapor pressures (moisture levels) without visible surface condensation on windows. In older building enclosures with less advanced glazing systems, visible condensation on the windows often alerted occupants to the need for ventilation to flush out interior moisture (so they opened the windows).

Concealed Condensation

The use of thermal insulation in wall cavities increases interior surface temperatures in heating climates, reducing the likelihood of interior surface mold, mildew and condensation. However, the use of thermal insulation also reduces the heat loss from the conditioned space into the wall cavities, decreasing the temperature in the wall cavities and therefore increasing the likelihood of concealed condensation. The first condensing surface in a wall cavity in a heating climate is typically the inner surface of the exterior sheathing, the "back side" of plywood or fiberboard. As the insulation value is increased in the wall cavities, so does the potential for hidden condensation.

Concealed condensation can be controlled by either or both of the following strategies:

- Reducing the entry of moisture into the wall cavities (e.g., by controlling infiltration and/or exfiltration of moisture-laden air)
- Elevating the temperature of the first condensing surface. In heating climate locations, this change can be made by installing exterior insulation (assuming that no significant wind-washing is occurring). In cooling climate locations, this change an be made by installing insulating sheathing to the interior of the wall framing and between the wall framing and the interior gypsum board.