5.3.6 Condensation Control

Moisture which condenses on the interior of a building is unsightly and can cause damage to the building and its contents. Even more undesirable is the condensation of moisture within a building wall where it is not readily noticed until damage has occurred. Moisture accumulation can cause wood to rot and metal to corrode.

Fungi and biological growth such as molds have the potential to grow in the presence of moisture or at relative humidities on the wall surface of 70% or higher. In general a favorable combination of the following conditions are required for growths to germinate, sprulate, and grow:

1. Fungal spores settling on the surface
2. Oxygen availability
3. Optimal temperatures (40 to 100°F)
4. Nutrient availability
5. Moisture (liquid or vapor above 70%RH)

Although concrete does not provide nutrients for mold growth, nutrients may be abundant as dirt and dust particles on the surface of the concrete. The first four conditions are met in almost every building. So, the primary method in controlling biological growth is to avoid high humidities and surface condensation. The key is to manage moisture by adhering to sound construction practices that minimize the potential for condensation.

Guidance in this chapter to eliminate condensation and prevent mold is from three recognized sources.[1, 2, 3] and can be summarized as follows

1. Increase surface temperature or reduce moisture level in the air.
2. Install a vapor retarder or vapor resistant material on the inside of insulation in cold climates.
3. Install a vapor resistant material on the outside of insulation in warm climates.
4. Prevent or reduce air infiltration.
5. Prevent or reduce rainwater leakage.
6. Pressurize or depressurize the building, depending on the climate, so as to prevent warm, moist air from entering the building envelope.

Good quality concrete is not damaged by moisture-concrete walls actually gain strength if they stay moist.

5.3.6.1 Climates

Causes of condensation are predominantly climate dependent. The first cause occurs when outside conditions are cold and is due to moist interior air condensing on cold surfaces; locations with these conditions will be called "cold." The second cause occurs when outside conditions are warm and humid and is due to humid air entering the building and condensing on cooler surfaces; locations with these conditions will be called "warm." Generally either of these conditions requires weeks rather than a few days for problems to occur. Some locations experience long enough warm and cold seasons to develop both types of condensation; these climates will be called "mixed."

Buildings in drier climates generally have less condensation problems than those in more humid climates. Generally the U.S. can be divided into humid and dry by a north-south line drawn through the center of the state of Texas. Areas east are humid and those west are dry. The exception is the northwest, where the coast of Washington and Oregon are also humid; these locations are called "marine." In drier climates, moisture that gets on or into walls will tend to dry to the inside and outside more readily than in more humid climates. For instance, when The Disney Company built Disney World in Orlando in the 1970s, many of the structures were constructed of the same painted wood construction and practices prevalent in Disneyland in southern California. These structures did not hold up well in the warm humid climate of central Florida.

However, even though buildings are more forgiving in drier climates, condensation has the potential to occur in warm, cold, or mixed climates if walls are not properly designed.

1 *ASHRAE Handbook of Fundamentals* - 2001, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, Chapters 23, 24, and 25. www.ASHRAE.org
2 Treschsel, Heinz, *Moisture Control in Buildings*, Publication No. MNL 18, ASTM, West Conshohocken, PA, 1994. www.ASTM.org
3 Treschsel, Heinz, *Moisture Analysis and Condensation Control in Building Envelopes*, Publication No. MNL 40, ASTM, West Conshohocken, PA, 2001. www.ASTM.org

The different climate types are defined on the map in Fig. 5.3.19 and described in Table 5.3.11.

5.3.6.2 Sources of moisture

Moisture can enter building walls from the interior, exterior, soil, or the building materials themselves.

Interior sources of moisture include people, kitchen and restroom facilities, and industrial processes. The average person produces 2.6 pints per day through respiration and perspiration. This amount increases with physical activity. Nearly all of the water used for indoor plants enters the indoor air. Five to seven small plants release 1 pint per day of water. In residential facilities, a shower can contribute 0.3 pints per minute and a kitchen 5 pints per day for a family of four. Active vents that remove moist indoor air to the outdoors should be provided in showers and kitchens.

Industrial processes, storage of moist materials, swimming pools, commercial laundries, kitchens, and ice rinks all contribute to indoor sources of moisture. Buildings with these conditions should be designed for the particular moisture conditions anticipated. In all cases, guidelines of ANSI/ASHRAE Standard 62[4] should be followed for proper ventilation of indoor air.

Outdoor sources include precipitation and infiltration. Rain and melting snow cause problems when the ground against walls is not pitched to move water away, or when plants that require frequent watering are located near walls. Vegetation near buildings should be able to survive without watering or a buffer area of decorative gravel can be placed. Landscaping near buildings has led to automatic sprinkler systems that "water" building walls. Moisture from precipitation should be controlled to prevent it from entering the walls or building. A primary and secondary line of defense should always be provided. For instance if joint sealant is used to prevent precipitation from entering a wall, a second line of joint sealant should be provided behind the first to keep out moisture should the first deteriorate.

Infiltration of moist air is caused by several sources. Due to the stack effect in buildings (warm air rises), outdoor air enters the building through cracks and joints near the bottom of the building and exits near the top. This effect is greater for taller buildings. Also, heating and cooling systems should have adequate air intake systems. Otherwise when the system is operating and exhausting air, it will depressurize the building and air can be drawn into the building through cracks, joints, and building materials. When the moisture content of outdoor air is greater than the indoor air, for example in warm humid climates, infiltration and depressurization bring moisture into the building. Moist air also enters the building through cracks, joints, and building materials when the vapor pressure of the outdoor air is greater than the indoor air. Again, this occurs on warm humid days or cooler days with high relative humidity.

Soil has the potential to provide a continuous supply of moisture to concrete through slabs and foundations. Capillary breaks between the foundation and above grade walls can reduce this potential. The ground should be sloped away from buildings and adequate drainage and waterproofing should be provided. As land becomes more scarce and costly, more buildings are being built on less desirable sites that previously ponded water; drainage must be properly considered in these areas. Also, any water draining from adjacent sites onto the subject building site needs to be properly channeled away from buildings. Vapor retarders should be installed beneath all concrete floor slabs in direct contact with the concrete to prevent moisture from moving up into the building. The vapor retarder should be installed above a granular subbase layer and directly beneath the concrete slab.

Building materials contribute significantly to moisture inside buildings, known as "moisture of construction," during the first years after construction. Concrete contributes significant moisture since it starts as a saturated material. Precast concrete dries during storage and continues to dry in the built structure until the pores near the surface reach an equilibrium moisture content with the indoor air. Wood and materials stored outdoors are also contributors. Many buildings have noticeable condensation the first year after construction that will subside in subsequent years. Dehumidification and adequate ventilation can help alleviate condensation due to moisture of construction.

5.3.6.3 Condensation on surfaces

Causes. Condensation occurs on surfaces inside buildings when the surface temperature is less than the dew point of the indoor air. The dew point of the air depends on its relative humidity. Dew-point temperatures to the nearest °F for various temperatures and relative humidities are shown in Table 5.3.12. In the summer in humid climates the relative humidity (RH) of the indoor air is generally in the range of 50 to 80%. In the winter in cold climates the relative humidity of the indoor air is generally

4 *ANSI/ASHRAE Standard 62-2001 – Ventilation for Acceptable Indoor Air Quality*, American Society of Heating, Ventilating, and Air-Conditioning Engineers (ASHRAE), Atlanta. http://www.ashrae.org

in the range of 20 to 40%.

Relative humidity is the ratio of the amount moisture in the air to the amount of moisture the air can hold (saturation). Colder air holds less moisture. In climates like Chicago the average relative humidity outdoors averages approximately 70%. Yet, the amount of moisture in the outdoor air is much less in the winter because the air holds less moisture. When this drier air is brought inside and heated up, the resulting relative humidity at 70°F is low; often in the range of 15 to 25%.

Example 5.3.3 – Condensation on a beverage can. Condensation may occur on a beverage can inside of a 75ºF building during the summer, but not at the same temperature in the winter. In the summer at 75ºF and 80%RH, the dew point is 68ºF. If the temperature of the can is less than 68ºF, condensation will occur on the can. In winter at 75ºF and 30%RH, the dew point is 42ºF. If the can is less than 42ºF condensation will occur on the can. Also, at the low RH in the winter, moisture that would condense on the can will evaporate quickly and may not be noticed.

Condensation on surfaces occurs most frequently due to cool indoor surface temperatures or high indoor humidity levels. These can be the result of many factors:

1. Inadequate heating and ventilation can result in cooler surface temperatures near the bottom of walls. Heating must be provided near floor level or with enough circulation to heat the lower portion of rooms.
2. Furniture or partitions placed up against walls may prevent adequate heating or air flow and produce cool surfaces.
3. Closets, which are rarely conditioned, can also have inadequate ventilation and cool surfaces.
4. Insufficient, damaged, or wet wall insulation can cause cool surfaces.
5. Thermal bridges, or areas of the wall that are not insulated as well as others, can also produce cooler surface temperatures.
6. High humidity caused by swimming pools, ice rinks, or industrial processes can cause condensation on indoor surfaces.
7. Cold air from air-conditioners blowing in the region of warm humid air can cause condensation on indoor surfaces.

The potential for condensation can be determined if wall temperatures and relative humidity of the air are known. The temperature gradient through any portion of a wall is directly proportional to its thermal resistance. Therefore, the temperature gradient Δt_n through a material with a thermal resistance R_n can be calculated using Equation 5.3.5:

$$\Delta t_n = R_n \cdot (t_i - t_o)/ R_T \qquad \text{Equation 5.3.5}$$

where:

Δt_n = temperature gradient or drop through material "n"

R_n = thermal resistance of material "n"

t_i = indoor air temperature

t_o = outdoor air temperature

R_T = thermal resistance of wall including air film resistances

The calculation of the temperature gradient profile through a wall assembly due to a temperature difference between indoors and outdoors can be used to determine whether there may be a problem with condensation or differential thermal movement. The temperature gradient alone is not sufficient to accurately locate the dew point within the assembly but it can be used as a guide for determining where condensation may occur from exfiltrating or infiltrating air. The assumption of steady-state conditions in this method is seldom satisfied due to fluctuations in temperatures within the wall. Nevertheless, the calculation is useful to flag potential problems.

Examples are provided for condensation on a cool surface in winter and summer.

Example 5.3.4 – Winter surface condensation due to inadequate heat or air distribution

Assume that, due to poor air circulation, the indoor air conditions are 75ºF and 30%RH near the top of the wall and 40ºF with an equal amount of moisture in the air near the bottom. This example is the same as the beverage can, Example 5.3.3; condensation will occur if the temperature of the wall is less than 42ºF. This can be prevented by providing adequate heating and ventilation along the full height of all walls.

Example 5.3.5 – Winter surface condensation due to not enough insulation

Assume the indoor air conditions are 70ºF and 35%RH and the average outdoor temperature for the day is 20ºF. Assume the wall is an insulated concrete sandwich panel from the previous thermal resistance calculation, Example 5.3.1. Compare this to a wall with no insulation. First we will determine the temperatures of the wall with insulation.

The thermal resistance of the wall, R_T, equals 7.11. The temperature difference across the wall, $t_i - t_o$, equals 70ºF – 20ºF = 50ºF. The temperature difference across any layer is calculated using Equation 5.3.5. The temperature difference across the air film equals 0.17(50) / 7.11 or 1ºF. The remaining temperature differences are calculated in the same manner as shown on the previous page. The temperature differences are subtracted from the indoor air temperature (or added to the outdoor temperature) to determine temperatures at boundaries between materials and are shown above in the right column. The inside surface of the wall, between the concrete and the inside air film, is 65ºF.

Shown above is the determination of the thermal resistance and temperatures of an uninsulated wall.

Note that the air temperature of the room is 70ºF and the temperature of the insulated wall surface inside the room is 65ºF while that of the uninsulated wall surface is 39ºF. The surface film resistance plays a much larger role in an uninsulated wall. The temperature gradient across the inside air film is 5ºF for the insulated wall and 31ºF for the uninsulated wall. The dew point of air at 70ºF and 35%RH is 42ºF. Since the inside surface of the uninsulated wall is 39ºF, condensation will form on the inside surface.

Also note that the average outdoor air temperature for the day was used in calculations. This average rather than the lowest daily temperature was used for two reasons. First, thermal mass of the concrete will tend to moderate the indoor surface temperature so that using an extreme temperature expected for just a few hours may be too conservative. Secondly, if a condensation occurrence is predicted for only a few hours, it will often occur and evaporate without causing problems.

Thermal bridges, such as a full thickness of concrete along panel edges, will behave similar to the uninsulated wall in Example 5.3.5. Thermal bridges may also occur at;

- Junctions of floors and walls, walls and ceilings, walls and roofs
- Around wall or roof openings
- At perimeters of slabs on grade
- At connections, if insulation is penetrated
- Any place metal, concrete, or a highly conductive material penetrates an insulation layer, such as metal shear connectors

Condensation can develop at these locations especially if they are in corners or portions of a building that receive poor ventilation.

Example 5.3.6 – Summer surface condensation

Condensation on wall surfaces also occurs in summer conditions. Cold air from air-conditioners blowing in the region of warm humid air can cause condensation on indoor surfaces. This most frequently happens when wall air-conditioner units are placed near window or door frames that allow humid air to enter the conditioned space.

Assume the average daily outdoor conditions are 80ºF and 75%RH. Assume this air can enter a room in a gap between the top of an air-conditioning unit and the bottom of a window. Assume the air conditioning unit blows enough cool air in the vicinity of a wall so that the wall surface temperature is 65ºF. Since the dew point of the moist air is 71ºF, condensate will form on the cool wall surface. This illustrates the need to provide adequate joint sealing to prevent the entry of humid air.

Prevention of Condensation on Wall Surfaces. All air in buildings contains water vapor. If the inside surface temperature of a wall is too cold, the air contacting this surface will be cooled below its dew-point temperature and water will condense on that surface. Condensation on interior room surfaces can be controlled both by suitable construction and by precautions such as: (1) reducing the interior RH or dew point temperature by dehumidification equipment or ventilation; or (2) raising the temperatures of interior surfaces that are below the dew point, generally by use of insulation.

The interior air-dew point temperature can be lowered by removing moisture from the air, either through ventilation or dehumidification. Adequate surface temperatures can be maintained during the winter by incorporating sufficient thermal insulation, using double glazing, circulating warm air over the surfaces, or directly heating the surfaces, and by paying proper attention during design to the prevention of thermal bridging.

Fig. 5.3.19 Climate zones for moisture.

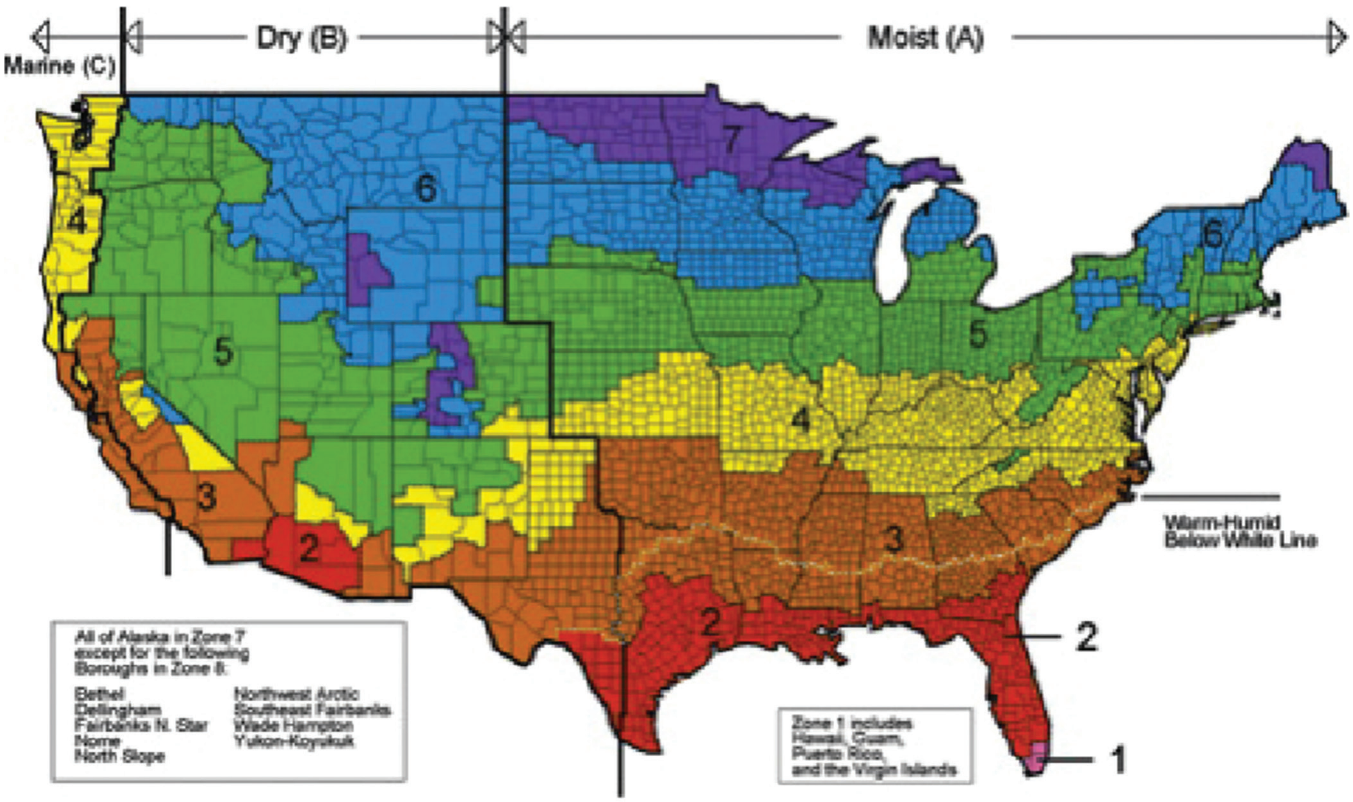

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Table 5.3.11 Climate Zones for Moisture.

Zone No.	Description	Representative U.S. Cities
1A, 2A, and 3A south of the humid line	Warm, humid	Miami, FL; Houston, TX
2B	Warm, dry	Phoenix, AZ
3A north of the humid line, 4A	Mixed, humid	Memphis, TN; Baltimore, MD
3B, 3C, 4B	Mixed, dry	El Paso, TX; San Francisco, CA; Albuquerque, NM
4C*	Cool, marine	Salem, OR
5A, 6A*	Cold, humid	Chicago, IL; Burlington, VT;
5B, 6B*	Cold, dry	Boise, ID; Helena, MT
7*	Very cold	Duluth, MN
8*	Subarctic	Fairbanks, AK

*For Canadian locations, climate zones are defined on the basis of Heating Degree Days Base 65 °F (HDD65F):

Zone 4C: 3600 < HDD65F ≤ 5400

Zone 5: 5400 < HDD65F ≤ 7200

Zone 6: 7200 < HDD65F ≤ 9000

Zone 7: 9000 < HDD65F ≤ 12,600

Zone 8: 12,600 < HDD65F

Table 5.3.12 Dew-Point Temperatures[1].

Dry Bulb or Room Temperature, °F	Relative Humidity (RH), %									
	10	20	30	40	50	60	70	80	90	100
40	-8	5	13	19	24	28	31	34	37	40
45	-4	9	17	23	28	32	36	39	42	45
50	-1	13	21	27	32	37	41	44	47	50
55	3	17	25	31	37	41	45	49	52	55
60	6	20	29	36	41	46	50	54	57	60
65	10	24	33	40	46	51	55	59	62	65
70	13	28	37	45	51	55	60	64	67	70
75	17	31	42	49	55	60	65	68	72	75
80	20	36	46	54	60	65	69	73	77	80
85	24	39	50	58	64	70	74	78	82	85
90	27	44	54	62	69	74	79	83	87	90

1 Temperatures are based on a barometric pressure of 29.92 in. Hg.

Thermal Resistance and Temperatures of Insulated Wall.

		R Winter	Temp. Difference, °F	Temp., °F
A.	Surface, outside air film	0.17	1	20
B.	Concrete, 2 in. (145 pcf)	0.13	1	21
C.	EPS insulation (1.25 pcf), 1 $^1/_2$ in.	6.00	42	22
D.	Concrete, 2 in. (145 pcf)	0.13	1	64
E.	Surface, inside air film	0.68	5	65
	Total	7.11	50	70
	$U = {}^1/_R$	0.14		

Thermal Resistance and Temperatures of Uninsulated Wall.

		R Winter	Temp. Difference, °F	Temp., °F
A.	Surface, outside air film	0.17	8	20
B.	Concrete, 4 in. (145 pcf)	0.25	11	28
C.	Surface, inside air film	0.68	31	39
	Total	1.10	50	70
	$U = {}^1/_R$	0.91		