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An American National Standard

# Standard Guide for Limiting Water-Induced Damage to Buildings[1]

This standard is issued under the fixed designation E 241; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

$\epsilon^1$ NOTE—Editorial changes were made throughout in November 2001.

## 1. Scope

1.1 This guide concerns building design, construction, commissioning, operation and maintenance.

1.2 This guide addresses the need for systematic evaluation of factors that can result in moisture-induced damage to a building or its components. Although of great potential importance, serviceability issues which are often, but not necessarily, related to physical damage of the building or its components (for example indoor air quality or electrical safety) are not directly addressed in this guide.

1.3 The emphasis of this guide is on low-rise buildings. Portions of this guide, in particular sections 5, 6, and 7, may also be applicable to high-rise buildings.

1.4 This standard is not intended for direct use in codes and specifications. It does not attempt to prescribe acceptable limits of damage. Buildings intended for different uses may have different service life expectancies, and expected service lives of different components within a given building often differ. Furthermore, some building owners may be satisfied with substantially shorter service life expectancies of building components or of the entire building than other building owners. Lastly, the level of damage that renders a component unserviceable may vary with the type of component, the degree to which failure of the component is critical (for example whether failure constitutes a life-safety hazard), and the judgement (i.e. tolerance for damage) of the building owner. For the reasons stated in this paragraph, prescribing limits of damage would require listing many pages of exceptions and qualifiers and is beyond the scope of this standard.

1.5 *This standard does not purport to address the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 168 Terminology Relating to Thermal Insulating Materials[2]
C 717 Terminology of Building Seals and Sealants[3]
C 755 Practice for Selection of Vapor Retarders for Thermal Insulation[2]
C 1193 Guide for Use of Joint Sealants[3]
D 1079 Terminology Relating to Roofing, Waterproofing, and Bituminous Materials[4]
E 331 Test Method for Water Penetration of Exterior Windows, Curtain Walls and Doors by Uniform Static Air Pressure Difference[5]
E 547 Test Method for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Cyclic Static Air Pressure Differential[5]
E 631 Terminology of Building Constructions[5]
E 632 Practice for Developing Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials[6]
E 1105 Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic Static Air Pressure Difference[5]
E 1643 Practice for Installation of Water Vapor Retarders Used in Contact with Earth or Granular Fills and Concrete Slabs[5]
E 1677 Specification for an Air Retarder Material or System for Low-Rise Framed Building Walls[5]
E 1745 Specification for Water Vapor Retarders Used in Contact with Soil or Granular Fill Under Concrete Slabs[5]

2.2 *Other Documents:*

ASHRAE Handbook of Fundamentals (1997) Chapter 22: Thermal and moisture control in insulated assemblies - fundamentals. Amer. Soc. of Heating Refrigerating, and Air Conditioning Engineers, Atlanta, GA.
ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy

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[2] *Annual Book of ASTM Standards*, Vol 04.06.

[3] *Annual Book of ASTM Standards*, Vol 04.07.

[4] *Annual Book of ASTM Standards*, Vol 04.04.

[5] *Annual Book of ASTM Standards*, Vol 04.11.

[6] *Annual Book of ASTM Standards*, Vol 14.04.

ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality

ASHRAE Technical Data Bulletin Vol. 10 Number 3. Recommended Practices for Controlling Moisture in Crawl Spaces, Amer. Soc. of Heating Refrigerating and Air Conditioning Engineers, Atlanta, GA., 1994.

Bateman, R. Nail-On Windows: Installation & Flashing Procedures for Windows & Sliding Glass Doors. DTA, Inc., Mill Valley, CA. 1995.

Connolly, J. "Humidity and Building Materials" in Proceedings: Bugs, Mold & Rot II (W. Rose and A. TenWolde, eds). National Institute of Building Sciences, Washington DC. 1993.

Lstiburek, J. and J. Carmody. "Moisture Control Handbook: New, Low-rise, Residential Construction", prepared for U. S. Dept. of Energy. 1991.

Trechsel, H. (ed.) "Moisture Control in Buildings" American Society for Testing and Materials, ASTM MNL 18, West Conshohocken, PA, 1994.

Timusk, J., Seskus, A., and K. Linger. 1992. A systems approach to extend the limit of envelope performance. In Proceedings: Thermal Performance of the Exterior Envelopes of Buildings V. Amer. Soc. of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA.

## 3. Terminology

3.1 *Standard Definitions*—Refer to Terminologies C 168, C 717, D 1079, and E 631 for definitions of general terms. Three definitions from C 168 are reiterated (verbatim) in 3.1.1-3.1.3.

3.1.1 *vapor retarder (barrier)*, *n*—a material or system that adequately impedes the transmission of water vapor under specified conditions.

3.1.1.1 *Discussion*—For low-rise residential construction, materials or components with a water vapor permeance not exceeding one perm are generally considered vapor retarders (see Practice C 755).

3.1.2 *water vapor permeance*, *n*—the time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

3.1.2.1 *Discussion*—Permeance is a performance evaluation and not a property of a material.

3.1.3 *water vapor permeability*, *n*—the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

3.1.3.1 *Discussion*—Permeability is a property of a material. Permeability is the arithmetic product of permeance and thickness.

3.2 *Other definitions found in ASTM Standards:*

3.2.1 *air retarder*, *n*—a material or system in building construction that is designed and installed to reduce air leakage either into or through an opaque wall or across a ceiling.

NOTE 1—Source of this definition is ASTM D 1677.

3.2.2 *opaque wall*, *n*—exposed areas of a wall that enclose conditioned space, except openings for windows, doors and building service systems.

NOTE 2—Source of this definition is ASTM D 1677.

3.3 *Consensus Definitions from Other Sources:* The following definitions are taken verbatim from the ASHRAE Handbook of Fundamentals (1997).

3.3.1 *ventilation*, *n*—the intentional introduction of air from the outside of a building.

3.3.2 *infiltration*, *n*—the uncontrolled flow of outdoor air into a building through cracks and other unintentional openings and through the normal use of exterior doors for entrance and egress.

3.3.3 *exfiltration*, *n*—the uncontrolled flow of indoor air out of a building through cracks and other unintentional openings and through the normal use of exterior doors for entrance and egress.

3.4 *Definitions of Terms Specific to This Standard:*

3.4.1 *air leakage*, *n*—infiltration or exfiltration, in other words uncontrolled air flow into or out of a building through cracks and other unintentional openings and through normal use of exterior doors for entrance and egress.

3.4.2 *building component*, *n*—an inclusive term to collectively refer to building materials, products, or assemblies.

3.4.3 *capillary break*, *n*—a term applied to a material, most commonly a synthetic membrane material, used to limit liquid water transfer by diffusion or capillary suction from wet ground or from a wet or damp building component to another building component that can absorb liquid water.

3.4.3.1 *Discussion*—Capillary breaks may also be composed of corrosion-resistant sheet metal, asphalt impregnated and coated felt, or where lesser degrees of resistance to capillary transfer are required, asphalt-impregnated felt.

3.4.4 *critical moisture content*, *n*—a moisture condition parameter. This parameter is expressed as a moisture content level above which immediate or virtually immediate damage will occur to a building component at a given temperature, such that the level of damage is deemed unacceptable.

3.4.5 *critical cumulative exposure time*, *n*—a moisture condition parameter, this parameter is expressed as a time sum when moisture conditions are above a level that results in cumulative damage to a building component, such that the level of cumulative damage is deemed unacceptable.

3.4.5.1 *Discussion*—cumulative damage to a component may occur over a range of moisture and temperature combinations, and damage is frequently more rapid at some combinations than at others. The differing rate of damage accumulation at different sets of conditions is accounted for with intensity factors, which are discussed in Chapter 26 of ASTM MNL 18.

3.4.6 *durability*, *n*—in constructions, the capacity of a building component or a construction to remain serviceable as intended with usual and customary operation and maintenance during the designed service-life under anticipated internal and external environments.

3.4.7 *flashing*, *n*—a term applied to elements, most commonly fabricated of sheet metal, but which may also be fabricated of synthetic materials, used at interruptions and terminations of water shedding systems of roofs and walls, and intended to prevent intrusion of liquid water at these points.

3.4.8 *limit*, *v*—to keep the value or level of some parameter, which is recognized as being problematic or potentially problematic, below a value or level which is deemed to be objectionable.

3.4.9 *limit state*, *n*—a value which expresses a moisture condition parameter, generally a critical moisture content or a critical cumulative exposure time, that is deemed to be at the border of what is acceptable, and beyond which an unacceptable level of damage to a building component may be expected.

3.4.10 *perm*, *n*—the time rate of water vapor migration by diffusion through a material or component equal to 1 grain per hour, square foot, inch of mercury vapor pressure difference. In SI units, one perm is 57.2 ng/(Pa·s·$m^2$).

3.4.11 *serviceability*, *n*—in a construction, the capacity of a building component or a construction to perform the function(s) for which it was designed and constructed.

3.4.12 *water or moisture*, *n*—water as liquid, vapor, or solid (ice, frost, or snow) in any combination or in transition.

## 4. Significance and Use

4.1 Moisture degradation is frequently a significant factor that either limits the useful life of a building or necessitates costly repairs. Examples of moisture degradation include: 1) decay of wood-based materials, 2) spalling of masonry caused by freeze-thaw cycles, 3) damage to gypsum plasters by dissolution, 4) corrosion of metals, 5) damage due to expansion of materials or components (by swelling due to moisture pickup, or by expansion due to corrosion, hydration, or delayed ettringite formation), 6) spalling and degradation caused by salt migration, 7) failure of finishes and 8) creep deformation and reduction in strength or stiffness.

4.1.1 Moisture accumulation within construction components or constructions may adversely affect serviceability of a building, without necessarily causing immediate and serious degradation of the construction components. Examples of such serviceability issues are: 1) indoor air quality, 2) electrical safety, 3) degradation of thermal performance of insulations and 4) decline in physical appearance. Mold or mildew growth can influence indoor air quality and physical appearance. With some components, in particular interior surface finishes, mold or mildew growth may limit service life of the component. Moisture conditions that affect serviceability issues can frequently be expected, unless corrected, to eventually result in degradation of the building or its components. This guide does not attempt however to address serviceability issues that could be corrected by cleaning and change in building operation, and that would not require repair or replacement of components to return the building (or portions or components of the building) to serviceability.

4.2 Prevention of water-induced damage must be considered throughout the construction process including the various stages of the design process, construction, and building commissioning. It must also be considered in building operation and maintenance, and when the building is renovated, rehabilitated or undergoes a change in use.

4.3 This guide is intended to alert designers and builders, and also building owners and managers, to potential damages that may be induced by water, regardless of its source. This guide discusses moisture sources and moisture migration. Limit states (or specific moisture conditions that are likely to impact construction or component durability), and design methods are also cursorily discussed. Examples of practices that enhance durability are listed and discussed, as are examples of constructions or circumstances to avoid. The examples listed are not all-inclusive. Lastly, field check lists are given. The checklists are not intended for use as is, but as guides for development of checklists which may vary with specific building designs and climates.

## 5. Moisture Sources and Migration

5.1 Moisture sources for buildings can be broadly classified as follows: (1) surface runoff of precipitation from land areas, (2) ground water or wet soil, (3) precipitation or irrigation water that falls on the building, (4) indoor humidity, (5) outdoor humidity, (6) moisture from use of wet building materials or construction under wet conditions and (7) errors, accidents and maintenance problems associated with indoor plumbing. At a given instant of time the categories are distinct from each other. Water can change phase and can be transported over space by various mechanisms. Water may therefore be expected to move between categories over time, blurring the distinctions between categories. Chapter 8 of ASTM MNL 18 provides quantitative estimates of potential moisture load from various sources.

5.1.1 High indoor humidity during winter is often a major cause of moisture problems in cold or temperate climates. Moisture-induced damage may be expected unless the building is designed to tolerate the levels of indoor humidity that occur in use. Conversely, moisture induced damage may be expected unless indoor humidity is kept within limits that the building will tolerate. Buildings should be designed and built so as to tolerate indoor humidity levels commensurate with their intended use. For some buildings, (for example: those intended for habitation by persons with certain medical conditions or those housing swimming pools or textile production equipment), the levels of indoor humidity which the building should be expected to tolerate are moderately high, even if the building is located in a cold climate. Conversely however, most buildings are not designed nor built to tolerate high indoor humidities during winter. It is therefore unreasonable to expect such buildings to perform adequately if operated at high indoor humidities during winter.

5.1.1.1 The potential for indoor humidity to cause damage depends on the local climate. Occupant density, that is number of occupants per given unit of space, and occupant activities frequently have a large influence on indoor humidity levels. Among occupant activities that influence indoor humidity, cooking, bathing and laundry activities, and use of unvented combustion appliances are those most likely to be significant. Air exchange between the living space and the exterior can significantly lower indoor humidity levels during winter in temperate climates. Control of indoor humidity is discussed in greater detail in 8.3 and its subsections.

5.1.1.2 Mathematical evaluation tools (see 7.1.2 and 7.1.3) can be used to identify if a given building design in a given climate will tolerate a given level of indoor humidity, or alternatively, to estimate tolerable indoor relative humidities for a given building design and climate.

5.1.2 Although use of dry building materials is preferable, wet building materials are commonly used. With some building materials (for example cast-in-place concrete) a wet initial condition is an inherent characteristic of the material, and thus unavoidable. The influence of moisture from wet building materials must not be overlooked. With proper design, construction and operation, moisture from wet building materials can, within limits, be dissipated without causing damage.

5.1.2.1 When wood frame walls are constructed with wet building materials or under wet conditions, the walls should be allowed to dry by evaporation before they are enclosed. Wall designs that permit more rapid dissipation of moisture can accommodate being enclosed at higher moisture conditions than can wall designs with lower capacity to dissipate moisture. Computer models (7.1.2) can be helpful in predicting drying rate in walls enclosed at higher than ideal moisture contents.

5.2 Strategies to prevent or control moisture accumulation in buildings fall into three broad categories: 1) limit moisture sources, 2) minimize moisture entry into the building or building envelope, and 3) remove moisture from the building or building envelope. Moisture control strategies that combine these approaches are usually most effective.

5.3 Moisture can migrate by a variety of moisture transport mechanisms. A comprehensive treatment of moisture transport and storage may be found in Chapter 1 of the ASTM Manual MNL 18. The following mechanisms are most significant in building constructions and are listed in order of potential magnitude: 1) liquid flow by gravity, air pressure, surface tension, momentum and capillary suction, 2) movement of water vapor by air movement, 3) water vapor diffusion by vapor pressure differences. These transport mechanisms can deliver moisture into the building or the building envelope, in which cases it is desirable that they be controlled. These transport mechanisms can also act to remove moisture from the building or building envelope, in which cases they may be used to promote drying.

5.3.1 In control of moisture delivery to the building or building envelope, the transport mechanisms that have the potential for moving the greatest amounts of moisture should (where practical) be controlled first. In promotion of drying of the building or building envelope, the transport mechanisms that have the potential for moving the greatest amounts of moisture should (where practical) be utilized first.

5.4 Building assemblies can become wet in three ways: (1) moisture can enter from the exterior, (2) moisture can enter from the interior, or (3) the assembly can start out wet as a result of using wet building materials or building under wet conditions.

5.4.1 Moisture typically enters building assemblies from the exterior through three mechanisms: (1) liquid flow by gravity, air pressure, surface tension, momentum, or capillary suction, (2) movement of water vapor by air movement, or (3) water vapor diffusion by vapor pressure differences.

5.4.2 Moisture typically enters building assemblies from the interior through two mechanisms: (1) movement of water vapor by air movement, or (2) water vapor diffusion by vapor pressure differences.

5.4.3 Operation of mechanical equipment has not always been recognized for its potential influence on moisture transfer. This potential influence should not be overlooked. Most notably, air handling equipment can induce a moisture transport mechanism that is capable of moving large amounts of moisture, namely movement of water vapor by air movement. Unplanned pressurization or depressurization of buildings or portions of buildings by air handlers can result in substantial moisture accumulations in the building envelope.

5.5 Moisture can typically be removed (dried) to the exterior or the interior by three mechanisms: (1) liquid flow by gravity (drainage) or capillary suction, (2) movement of water vapor by air movement (ventilation), or (3) water vapor diffusion by vapor pressure differences.

5.5.1 Where condensation of water vapor or water leaks can occur, weep paths to drain liquid water to a place where it can be dissipated are often effective. Converting liquid water to vapor, and dissipating the vapor by air movement may also be practical.

## 6. Limit States

6.1 Identification of conditions that must be avoided in order to prevent degradation of building components is an important step in making design or operating decisions. However, precise guidelines for identification of such conditions are generally lacking. Rather rough estimates based on empirical experience are often used.

6.2 Time and temperature are factors that are inter-related with moisture level in the degradation of building components. The moisture/temperature/time combinations that result in material degradation furthermore vary with the type of material. For example, wood will not decay, even at elevated moisture content when its temperature is near or below freezing, and even at temperature conditions conducive to decay, wood can withstand intermittent wettings of short duration to elevated moisture contents without decay becoming established. Conversely, masonry units can generally be expected to withstand elevated moisture conditions at temperatures above freezing for extended time periods (conditions under which wood decay might be expected), but suffer damage if frozen in a saturated condition.

6.2.1 Many materials or constructions have threshold water contents below which deterioration may be slow enough to be negligible for designed life expectancy. As indicated in 6.1 these threshold values are often rather rough estimates. See Connolly (Nat'l Inst. of Bldg. Sci., 1993) for estimates.

6.2.2 The concepts of critical moisture content and critical cumulative exposure time (see Definitions) are discussed in Chapter 26 of ASTM MNL 18. Although these concepts are generally recognized by building scientists, organized use of these as limit states by designers has not yet become a well-recognized practice.

6.3 A limit state is frequently based on avoidance of damage to a component as the result of its getting wet. A limit state may also be based on avoidance of damage to a component as a result of moisture conditions in an adjacent component. For example, limiting moisture-induced dimensional change of plywood sheathing may be critical to prevent cracking of stucco cladding.

## 7. Design Evaluation Tools

7.1 Means for evaluating the design of building envelopes from the perspective of moisture management can be classified as follows: (1) conceptual, (2) mathematical using computer simulation models, and (3) mathematical using calculations that can be performed without computer software (sometimes referred to as manual design tools).

7.1.1 *Conceptual design evaluation*—This approach involves the following three-step procedure: (1) determine probable external and internal environmental loads (determine climate and interior design conditions), (2) determine the potential moisture transport mechanisms in each assembly, and (3) select moisture control strategies. This approach provides a qualitative perception of how a building will perform under the influence of all the moisture loads the building is likely to be subjected to. The Moisture Control Handbook (Lstiburek and Carmody, 1991) provides a more comprehensive treatment of this approach. Conceptual design evaluation can be used to select a construction for a given climate, as well as to evaluate how a proposed construction may perform in a given climate.

7.1.2 *Computer simulation models*—These models have been developed to quantitatively predict moisture and temperature conditions within proposed assemblies using boundary conditions representative for the climate and interior design conditions. These models mathematically model moisture and heat transfer mechanisms at the inner and outer surfaces of the assemblies and within the assemblies. Some of the models predict moisture transfer by air movement and liquid water flow as well as by vapor diffusion. Use of such models requires knowledge of building physics and of the limitations of the model used. Most models allow estimates of the duration of a set of temperature and moisture conditions within assemblies. A discussion of available models is found in Chapter 2 of ASTM Manual MNL 18.

7.1.3 *Manual design tools*—Like computer simulation models, these provide quantitative estimates of moisture conditions within building envelopes. They only account however for moisture transfer by vapor diffusion. Their focus is on predicting the occurrence of sustained condensation within building assemblies. The calculations for manual design tools can be easily performed with a handheld calculator. The traditional design tool used in North America is a manual design tool and is referred to as the dewpoint method. The dewpoint method is the method outlined in section A1.1 of ASTM C 755. The validity and usefulness of predictions made with manual design tools have limitations. Most notably, manual design tools do not provide estimates of the time period during which potentially damaging conditions may occur. A discussion of manual design tools is found in Chapter 11 of ASTM Manual MNL 18, and in Chapter 22 of the 1997 ASHRAE Handbook of Fundamentals.

## 8. Examples of Practices that Enhance Durability

8.1 *Drainage of Precipitation and Surface Runoff*:

8.1.1 *Surface grading*—Ground should slope away from walls so that precipitation runoff from land areas does not pond near the foundation.

8.1.2 *Building external drains*—Discharge from drains at ground level should be carried away from the foundation, and should flow away from it.

8.1.3 *Below-grade drainage systems*—In some cases below-grade drainage systems may be required. In some cases, dissipation of collected water by pumping will be required. Below grade drainage systems are discussed in Chapter 2 of The Moisture Control Handbook.

8.2 *Limiting Intrusion of Precipitation*

8.2.1 Precipitation has the potential for delivering exceptionally large moisture loads to buildings, and is usually the largest potential moisture source (see Chapter 8 of ASTM MNL 18). It is imperative that this source be controlled, specifically that precipitation be excluded from the building envelope. In some cases, entry of limited mounts of precipitation into the envelope can be tolerated provided that it is rapidly dissipated by drainage, or (typically more slowly) by evaporation.

8.2.1.1 Moisture from precipitation enters building envelopes almost exclusively in liquid form, either as rain or as melt water from ice or snow.

8.2.2 The water exposure of horizontal or sloped surfaces (i.e. roofs) is almost always greater than that of walls. Shedding and drainage of water from roof surfaces is imperative. These surfaces must essentially be water tight (i.e. not leak). Penetrations through water shedding membranes of roofs are common leakage points; flashings are almost always required at such penetrations. Design, installation and maintenance of roofs are very important. There is an entire Volume (Vol 4.04) of the ASTM Annual Book of Standards that contains standards concerning roofing and waterproofing. Therefore, a comprehensive treatment of these subjects is not attempted in this standard.

8.2.3 Water intrusion through building facades (in low rise construction, this primarily means walls) can be of substantial consequence. There are two broad strategies for controlling rainwater intrusion into walls: (1) reduce the amount of rainwater deposited on building walls, and (2) control rainwater that is deposited on building walls.

8.2.3.1 Reducing rainwater deposition on wall assemblies has traditionally been a function of siting and architectural design. The following measures have historically proven effective: (1) site buildings so they are sheltered from wind-driven rain, (2) provide roof overhangs and gutters or other piped roof drainage systems to shelter walls from direct rain exposure or roof runoff.

8.2.3.2 As suggested in 8.2.1, roof runoff is usually an exceptionally large potential water source. In temperate and cold climates, exposure to roof runoff is one of the most common causes of freeze-thaw spalling of masonry cladding systems. Wood and wood-based cladding systems are widely recognized as being incapable of performing adequately if exposed to roof runoff. Among the more common water intrusion points in walls are the interfaces of walls with roofs, especially with level or nearly-level roofs. Thresholds of doors that open to balconies represent one of the most common sites of serious water intrusion into walls. Serious water intrusion at these sites can generally be expected unless the balcony surface is pitched to drain water away from the wall. For the reasons stated in this paragraph, it is generally accepted that walls of buildings must not be exposed to roof runoff.

8.2.4 Walls are most susceptible to water intrusion at joints in and penetrations of the exterior cladding system. Joints between the cladding system and windows and doors are locations susceptible to water leakage. Junctures of walls with large horizontal or sloped surfaces (for example roofs, decks or balconies) are susceptible to leakage. Therefore, particular care is required at these locations.

8.2.5 Strategies for control of rainwater that is deposited on building walls can be broadly categorized as follows: (1) strategies to prevent water penetration of the outermost face of the wall system, (2) strategies to dissipate water that penetrates the outermost face of the wall system. Strategies in these two general categories often are effectively used in combination. Strategies for control of rainwater deposited on building walls are discussed in Chapter 2 of The Moisture Control Handbook. Further discussion on the subject, as well as recommendations concerning design details are found in Nail-On Windows (Bateman, 1995). It is important that the strategy or strategies selected by the designer be clearly understood by construction contractors and those responsible for maintenance of the building.

8.2.5.1 *Exterior Mechanicals*—Penetrations of this type (for example electrical equipment) should be of a type suited for exterior service and be installed with adequate moisture seals.

8.2.5.2 *Windows*—Window systems that have been tested for water penetration are recommended. See Test Methods E 331 and E 547. Proper integration of windows into wall systems is essential. Where a large number of windows of the same type are to be installed, in-place testing of the first installations by Method E 1105 (to identify if there are installation deficiencies) is desirable.

8.2.5.3 *Sealant Joints*—In contrast to high-rise construction, design of sealant joints in low-rise construction has generally not become a well-developed discipline. Design of reliable sealant joints can include many factors such as: sealant-substrate compatibility, avoidance of 3–sided adhesion, joint geometry and anticipated movements in joints (see Standard Guide C 1193). Workmanship, including conditions under which sealant joints are installed, is also important. Maintenance of sealant joints must not be overlooked, since anticipated life of sealant joints will almost certainly be substantially less than design life of the building.

8.3 *Control of Indoor Humidity*

8.3.1 From the standpoint of building durability, indoor humidity control is primarily of concern during winter in temperate or cold climates. It may also be of concern however in air conditioned buildings in hot humid climates, particularly if the building is designed to dry toward the interior. In mild weather in any climate, humidity control may be of importance from the standpoint of preservation of property within the structure or from the standpoint of indoor air quality (for example preventing mold growth that releases spores and musty odors or inhibiting the propagation of dust mites), but generally is not of great concern to durability of the building structure.

8.3.2 Indoor humidity can be limited by controlling moisture sources or by removing humidity by air exchange with the exterior or by dehumidification.

8.3.3 As indicated in 5.1.1 and 8.3.1, the indoor humidity (RH) level that a given building will tolerate is climate-dependent. ASHRAE 55 recommends that for human comfort, dewpoint temperature of occupied spaces not fall below 36° F (2° C). Over the dry-bulb temperature range of 67°-74° F (19°-23° C) (the approximate temperature range outlined in ASHRAE 55 for winter comfort) this corresponds to an indoor RH range of approximately 32–25%. In contrast, experience and computer simulation models suggest that damaging moisture accumulations can be expected in many buildings of customary design in cold climates if winter indoor RH in heated buildings is maintained at levels in excess of 40%. These observations suggest that it is reasonable to expect buildings of customary design in cold climates to tolerate indoor RH levels above the minimum for human comfort, but not much above such levels. When higher indoor humidity levels are necessary or desired in cold climates, the building must be carefully designed, built, and operated to tolerate such levels.

8.3.4 In most hetaing climates during cool or cold weather, air exchange with the exterior can significantly reduce indoor humidity (Chapter 15 of ASTM MNL 18 and Chapter 23 of ASHRAE Handbook of Fundamentals). Chapter 23 of the ASHRAE Handbook of Fundamentals suggests that at normal rates for residential occupancy and moisture generation and in all but mild humid climates, ventilation to a level of 0.35 air changes per hour (as recommended in ASHRAE Standard 62, Ventilation for Acceptable Air Quality) will usually be sufficient to prevent excessive indoor humidity. Mechanical dehumidification is rarely used for indoor humidity control during cold weather. In mild humid climates, air exchange with the exterior may be of limited effectiveness for control of indoor humidity. In these climates, dehumidification may be more effective than ventilation for controlling indoor RH, but as indicated in 8.3.1 is more likely to be deemed necessary for reasons other than that of durability of the building structure.

8.3.4.1 In designing for provision of air exchange between the living space and the exterior, energy efficiency and air quality considerations as well as durability considerations are usually important.

8.3.4.2 In buildings constructed prior to 1970, air exchange between building interiors and the exterior during winter in temperate and cold climates has occurred primarily by a combination of infiltration (much of which occurred through fenestration units) and escape of air up chimneys (a combination of air movement through furnaces, draft hoods, and barometric draft dampers). The effect of chimney draft has often been sufficiently great that the buildings have operated at a negative air pressure relative to the exterior, causing air leakage through the building envelope to be predominantly infiltrative. Infiltrative air leakage is not capable of transporting interior moisture into the envelope. Air exchange rates have been uncontrolled, responding to air temperature differences and wind effects. During cold windy weather, air exchange rates have often been well in excess of the amounts recommended as necessary by ASHRAE Standard 62. In some cases, the air exchange rates during cold weather have been overly effective at reducing indoor humidity levels (sometimes to below the comfort range outlined in ASHRAE Standard 55). Although substantially less than ideal from an energy use perspective, buildings that operate in this traditional mode generally have not suffered significant moisture-induced durability problems. Many existing buildings, perhaps a majority of existing buildings, operate in this traditional mode during cold weather.

8.3.4.3 Since the 1970's, buildings have generally been built so that they can be heated with less energy. For a building of a given size, the increased energy efficiency has resulted in furnaces of smaller size and/or furnaces that run a lower percentage of the time during the heating season. The result has generally been a greatly reduced rate of furnace-induced exhaust of interior air via the chimney. In addition, the building envelope, including fenestration units, have become more resistant to air leakage. The result is that some buildings now operate at much lower air exchange rates than recommended by ASHRAE Standard 62, and the low air exchange rates have in some cases resulted in excessive indoor humidity levels. With reduced rates of furnace-induced exhaust of indoor air, the probability for negative pressurization of the building is reduced. This in turn means that a greater proportion of the building's air leakage (than had previously been the case) is likely to be exfiltration.

8.3.4.3.1 Building scientists generally agree that modem buildings in heating climates that are reasonably energy efficient will in many cases have insufficient air exchange rates (from the perspective of either indoor air quality, as outlined in ASHRAE Standard 62, or from the perspective of indoor humidity control) unless they are provided with some type of ventilation system. From a prescriptive standpoint, there is not full concensus concerning what constitutes an adequate ventilation system. Powered ventilation systems, passive stack vents, and passive ventilation by use of window trickle ventilators may all potentially provide for adequate ventilation rates. In North America there is more practical experience with powered ventilation systems than with the other two alternatives. Powered ventilation systems are generally recognized as being easier to control that the alternative systems. If powered ventilation or passive stack vents are chosen, the air exchange passageway(s) for these systems should be directly between the interior and exterior of the building; no passageway should terminate within the building's thermal envelope. Fans in kitchens or bathrooms (which are frequently thought of as spot ventilation devices) have been used effectively as building ventilation systems when carefully selected and installed and properly operated by occupants. Use of heat recovery ventilating systems may be justified where energy use is a concern, although heat losses associated with the ventilation levels prescribed as minimums by ASHRAE Standard 62 are generally not excessive. Design of ventilation systems is its own discipline and beyond the scope of this standard.

8.3.5 Spot ventilation (at localized sources of indoor humidity) is recognized as a generally effective method to help control indoor humidity levels in buildings.

8.3.5.1 Venting of clothes dryers to the exterior is a form of spot ventilation, and is recommended for all climates. In modem energy-efficient houses, efforts to assure that clothes dryers are provided with adequate make-up air are recommended.

8.3.5.2 Spot ventilation in kitchens and bathrooms is common practice and is most commonly accomplished with exhaust fans, although it may also be accomplished with operable windows. Spot ventilation has the theoretical potential to dissipate given quantities of indoor humidity efficiently (i.e. with lower quantities of air exchange than whole-building ventilation). If moisture from the source becomes well mixed into the interior air however before the fan or window can exhaust it, the theoretical advantage of spot ventilation is not attained.

8.3.5.2.1 The effective capacity of exhaust fans can be substantially reduced by long exhaust duct runs, bends in the duct runs, and use of duct materials that restrict air flow through them.

8.3.5.2.2 High capacity kitchen exhaust fans have become popular in some (generally high-priced) residences. These are generally very effective for removal of kitchen-generated moisture, but require that adequate provision be made for make-up air. If adequate provision for make up air is not made, they may not vent effectively, and may cause dangerous levels of depressurization within the building. If depressurization in the location of natural-draft combustion appliances exceeds approximately 5 Pascals, back-drafting of the appliances may result. Back-drafting has also been observed at negative pressures of smaller than 5 Pascals. In some cases, installation of safety interlocks, which prevent operation of natural draft combustion appliances when high capacity kitchen exhaust fans are in operation, may be justified.

8.3.5.2.3 Exhaust from powered ventilating equipment should be ducted all the way to the outdoors. Ducting may pass through locations that are cool or cold. When this occurs, precautions should be taken to prevent condensation in the ducting or to drain condensation that occurs in the ducting.

8.3.5.2.4 In a significant number of older houses, an operable window is the only available means for spot ventilation of bathrooms. The potential for dissipation of moisture from bathrooms via operable windows is considerable in most climates, although occupants may fail to use them effectively for this purpose.

8.3.6 Latent (dehumidification) loads should be taken into account when sizing air conditioning (mechanical cooling) equipment. Although failure to do so generally does not result in degradation to the building structure, it can reasonably be expected to result in damage to interior surface finishes by mold or mildew growth. Oversizing cooling equipment can be expected to result in inadequate dehumidification in humid summer climates.

8.3.6.1 In many existing buildings, air conditioning equipment is oversized, and therefore unable to adequately control indoor humidity. In these cases, dehumidification equipment is often necessary, although as indicated in 8.3.6 usually for reasons other than durability of the building structure.

8.4 *Limiting Moisture Deposition within Assemblies by Air Movement*

8.4.1 *Driving forces*—Air migration occurs from air pressure differentials. These are generally induced by mechanical systems, temperature differentials, wind, or a combination of these factors.

8.4.1.1 *Mechanically-induced pressure differentials*—Air pressure differentials caused by mechanical air handlers will in most cases be easier to control than the other pressure differentials. In low-rise buildings these can be of greater magnitude than thermally-induced pressure differentials. They are usually of lesser magnitude than peak wind-induced pressure differentials, but of more sustained duration. Control measures include proper design of air handling systems, careful installation of ductwork to minimize duct leakage, and properly balancing the system when it is commissioned. Modifications either to the air handling system or to the building (for example addition of interior partitions) should be evaluated for their potential for creating air pressure differentials.

8.4.1.2 *Thermally-induced pressure differentials*—Thermally-induced pressure differentials generally cannot be prevented. Therefore the strategy used to control air movements created by these differentials is by construction that restricts air movement. In heating climates the potential for thermally-induced air movement from the heated interior to roof spaces is generally well recognized, as is its potential for transporting moisture into the roof space. Ceilings should thus be constructed so as to restrict air leakage across them. This includes sealing air leakage paths associated with mechanicals (for example ceiling light fixtures and plumbing and wiring chases).

8.4.1.3 *Wind-induced pressure differentials*—Assuming there is a prevailing wind direction, building siting and landscaping (planting of wind breaks) can limit a building's exposure to wind pressure differentials. Also assuming that there is a prevailing wind direction, building orientation may also influence predominant direction of wind-induced pressures on individual portions of the building. Potential changes in the neighborhood of the building regarding nearby trees and buildings may however make decisions regarding siting, windbreaks, and orientation of limited value for the entire design life of a building.

8.4.1.3.1 Wind can generally be expected to induce infiltration through exterior walls on the windward side of the building and exfiltration through exterior walls on the other sides of the building (see ASHRAE Handbook of Fundamentals). During cold winter days, the wetting potential to the building envelope of a given volume of exfiltrating air generally exceeds the drying potential of an equal volume of infiltrating air. Therefore, it is desirable to limit wind-induced air movement through assemblies in the thermal envelope. This is generally done by designing and constructing such assemblies so as restrict air leakage.

8.4.2 *Air leakage effects*

8.4.2.1 *Air leakage effects in cold climates*—In cold climates, exfiltration of indoor air through the building envelope can result in substantial moisture accumulation in the envelope. The degree to which exfiltrating air will deposit moisture in the envelope is influenced by interior humidity levels and by exterior temperature; lower indoor humidity levels and milder exterior temperatures reduce the potential. The characteristics of air exfiltration passageways can also influence the potential for moisture accumulation in the building envelope. With a passageway that allows for relatively large amounts of air to exit through the envelope in a concentrated area (i.e. a relatively small, direct and unobstructed passageway) the edges of the passageway may be warmed by the exfiltrating air, and the air may leave the building without depositing much of the moisture it contains within the building envelope. Although air leakage has the potential for depositing substantial quantities of moisture in building envelopes, it does not necessarily result in damaging accumulations. Substantial quantities of air leakage occur in many older buildings, yet damaging accumulations of moisture in the envelopes of these buildings are relatively rare, in large part because the air leakage is predominantly infiltrative and the indoor humidity levels are often very low (see 8.3.4.2).

8.4.2.1.1 Exfiltration across ceilings—One of the more significant exfiltration sites in many buildings, is between ceilings and attics. In some buildings in cold climates, ceiling exfiltration is a major factor in air exchange between the building interior and exterior. When indoor humidity is low, damaging moisture accumulations from exfiltration across the ceiling are relatively rare, but some moisture accumulation in roof sheathing and framing members during winter can be expected. Spectacular cases of winter moisture accumulation in attics, primarily as a result of exfiltration, (usually in cases where indoor humidity levels were moderately high), have occurred. When exfiltration across ceilings substantially influences the building's air exchange rate, it represents uncontrolled air exchange and thus may have a significant impact on heating costs. As indicated in 9.6.1.1, exfiltration across ceilings sometimes plays a role in ice dam formation on roofs.

8.4.2.2 *Air leakage effects in hot humid climates*—In hot humid climates, air infiltration through the envelopes of air conditioned buildings can result in substantial moisture accumulation within them.

8.4.2.3 *Limiting air leakage*—The two approaches to control of air leakage are: 1) control of driving pressure differentials, and 2) construction of the building envelope to restrict air leakage.

8.4.2.3.1 Control of pressure differentials— As indicated in 8.4.1.1, pressures induced by mechanical systems can be controlled through design, installation, commissioning, and operation of the mechanical systems. As indicated in 8.4.1.2 and 8.4.1.3, thermally-induced pressure differentials generally cannot be limited, and there are a limited number of things that can be done to control wind-induced pressure differentials.

8.4.2.3.2 Construction to restrict air movement—Air movement through assemblies and constructions can be restricted by a variety of means. Sheet membrane or panel materials may be used. Use of tape, caulk, gaskets or expanding foam sealants in conjunction with sheet membrane or panel materials usually appreciably increases the resistance of these systems to air leakage. Sprayed foam insulations are generally recognized as being effective at restricting air leakage through constructions. The potential for air leakage through constructions made with structural foam-core panels is generally expected to be small, and where air leakage occurs it can be expected to be via relatively direct passageways. Whatever system is used to restrict air leakage through the building envelope, sealing of joints in the system that may act as passageways is important. Where air retarder systems are used on opaque frame walls, conformance with Standard Specification E 1677 is recommended. Because passageways associated with plumbing and electrical systems are potential air leakage passageways, they should not be overlooked. Workmanship in installation of plumbing and electrical systems, and in sealing of leakage paths after their installation (and before enclosing walls) can be important in restricting air leakage.

8.5 *Limiting Moisture Uptake from Ground Water or Wet Soil*

8.5.1 There are three broad strategies for limiting moisture uptake from ground water or wet soil. These may be classified as follows: (1) limit deposition of surface water onto the soil near the building (see 8.1), (2) remove excessive soil moisture with below-grade drainage systems (see 8.1.3), and (3) isolate the building from soil moisture by use of vapor retarders and capillary breaks.

8.5.2 *Vapor Retarders on Exposed Earth in Crawl Spaces*—Use of vapor retarders to limit evaporation of soil moisture into the crawlspace air is recognized as one of the most effective means of preventing elevated moisture conditions in crawlspaces (see ASHRAE Technical Data Bulletin Vol. 10, #3). Vapor retarder sheets must resist biological attack and have adequate strength and impedance to vapor transmission.

8.5.3 *Vapor Retarders Under Concrete Slabs*—Vapor retarder sheets function as capillary breaks as well as vapor retarders under concrete slabs. These should be strong, resistant to biological attack, and have adequate impedance to moisture movement. Materials conforming to ASTM Standard Specification E 1745 are recommended. Installation should be in accordance with ASTM Standard Practice E 1643.

8.5.4 *Perimeter Foundation Walls*—Coating or membrane materials are frequently installed on the exterior of perimeter foundation walls to serve primarily as capillary breaks. Their use is recommended. During the first few years of a building's life when the concrete foundation is still fresh, the influence of these materials on moisture conditions on the interior side of perimeter basement walls will be less than in subsequent years.

8.5.4.1 Some coating or membrane materials for application to the exterior of perimeter foundation walls have been shown through testing as being able to prevent liquid water flow induced by hydrostatic pressure head. Because hydrostatic pressure head can structurally damage the foundation wall, it is preferable to prevent ponding of water at the foundation wall, rather than to rely on these materials or products to prevent liquid water flow by pressure head.

8.5.5 *Capillary breaks between slabs or concrete foundation walls and framing*—Such breaks (made of plastic film or corrosion-resistant sheet metal) are recommended, since it is usually difficult to assure that the concrete remains dry. Wood-based sheathing or siding manufacturers typically specify that their product not come in direct contact with masonry or concrete.

8.6 *Limiting Water Vapor Diffusion by use of Vapor Retarders*:

8.6.1 Where vapor retarders are required they should generally be placed on that side of the construction with the higher average annual temperature. Vapor retarders may be structural, may be integral with insulating materials (for example foam insulations) or may be in the form of thin sheets or coatings. Because of the potential for air movement to transfer appreciable quantities of water vapor, vapor retarders can be expected to be of limited effectiveness unless air movement is also controlled.

8.6.1.1 Use of computer models (7.1.2) permits logical decision making regarding use of vapor retarder materials and their placement in constructions. Manual design tools (7.1.3) may also be used, although use of computer simulation models is usually preferable.

8.6.1.2 In climates with high humidities and high temperature, especially where air conditioning is virtually continuous, the ingress of moisture may be limited by a vapor retarder system in the building envelope near the outer surface.

8.6.1.3 Exterior sheathings with low permeance and low insulating values may cause moisture accumulation problems in heating climates. If the exterior sheathing is an effective insulator however, it will prevent low temperatures (that would induce condensation) from occurring within the wall. Computer models or manual design tools (7.1.2 and 7.1.3) can be used to predict if moisture accumulation will or will not occur in planned wall constructions.

8.6.2 In building assemblies in which vapor retarders should be installed, the use of large continuous sheets is often preferable to that of smaller discontinuous sheet retarders (for example preapplied vapor retarders on fibrous batt or blanket insulation). Large continuous sheets, if carefully applied, may serve as air retarders as well as vapor retarders (see 8.6.1). Where smaller discontinuous sheets are used, the joints between them should be taped or otherwise sealed. Large panels of building material which are integral retarders or to which retarders are applied are likewise usually preferable to small discontinuous sheet retarders. If panels are used, joints between them should be sealed.

8.6.3 Where an interior vapor retarder is required, interior finishes with vapor retarding properties, or interior finishes to which vapor retarding materials have been applied may be used in lieu of sheet vapor retarders.

## 9. Examples of Constructions and Circumstances to be Avoided

9.1 *Inappropriate Building siting*

9.1.1 In areas that are prone to floods, building of structures may be inappropriate. Efforts at preventing moisture accumulation due to rainwater leakage, air movement, or vapor diffusion will have been wasted if the building is destroyed or extensively damaged by flooding.

9.1.1.1 In areas prone to flooding, building may be appropriate with special procedures and precautions, such as building on piers. Piers systems may however (depending on their design and the intensity of a flood) be undermined by moving waters or demolished by large pieces of floating or partially-submerged debris in moving flood waters. Building structures to withstand the rigors imposed by location in areas prone to flooding is a special discipline, and beyond the scope of this standard.

9.1.2 In areas of high water table certain building designs are inappropriate. For example, houses with full basements are usually not appropriate in areas of high water table.

9.2 *Inadequate Flashings and Curbs*

9.2.1 *Height*—Flashings and curbs of inadequate height should be avoided. Consideration should be given to peak rainfall, runoff, and wind velocities when selecting height of the vertical leg of flashings. Wind may blow water over the tops, and snow may drift higher than flashings or curbs to create leaks; some leaks may be of temporary duration but nevertheless cause severe unseen damage or start progressive leaks.

9.2.2 *Integration with cladding or roofing systems*—Failure to properly integrate flashings with roofing or cladding systems is a fairly common error, and must be avoided.

9.3 *Entrapments*

9.3.1 Rainwater leakage or condensation may cause substantial degradation of building components unless the water is dissipated. Building components that may become wet should be designed for dissipation of moisture. Building components that are built dry and will never be wetted may be constructed without planning for moisture dissipation from them. Assurance that a building component will never undergo wetting should however not be casually assumed, since rainwater leakage may migrate for appreciable distances from the source.

9.3.2 *Vapor Retarders on the Cold Side of a Construction*—Moisture accumulation at the vapor retarder may occur when it is on the cold side of a construction. In addition, the vapor retarder may prevent subsequent drying.

9.3.3 *Inappropriate use of Coatings and Paints*—Coatings and paints may act as vapor retarders and thereby prevent drying from the surface. Their use, particularly on the lower temperature side of a construction should involve consideration of their potential to prevent drying. In these situations, substitution of higher permeance coatings or paints for those of lower permeance is often an option.

9.3.4 *Inappropriate use of Sealants*— Caulking and sealing exterior walls of buildings should be done with caution so that intended passages for drainage of water (for example weepholes or planned omission of mortar joints) are not obstructed.

9.4 *Excessive Air Infiltration or Exfiltration Through the Building Envelope*

9.4.1 Air movement through a building's thermal envelope can potentially deposit substantial volumes of moisture within the thermal envelope. Therefore if air exchange between the interior and exterior is desired it should be done directly, and not through the building's thermal envelope. An exception to this recommendation can be made when the ventilating system is integrated into the structure in such a way that the direction of airflow through the envelope is never in a direction that would deposit moisture in the thermal envelope (see Timusk et. al., 1992). Also, unplanned air movements through the thermal envelope should be limited by means discussed in 8.4.2.3.

9.5 *High Thermal-Conductance Paths*

9.5.1 High thermal conductance paths may cause condensation within assemblies or constructions. These may occur at junctions of walls and ceilings, and walls and roofs; around wall or roof openings; and at perimeters of slabs on the ground. The impact of high-conductance paths should be considered at the design stage, and avoided where calculations indicate condensation is prone to occur.

9.5.2 *Window or Door Condensation*—Condensation on fenestration units generally poses serviceability problems, but may also cause degradation of the fenestration units themselves or wall components beneath the units if there is drainage of condensation from the units. Options for preventing condensation occurrence are (1) reduce indoor humidity, (2) chose units that contain thermal breaks or that are made from low conductance materials, and (3) consider double or triple glazing, or insulating glass units with low emittance glass, low conductance gas fills, or low conductance edge spacers, or combinations of these.

9.6 *Ice damming*

9.6.1 Ice damming prevents drainage from sloped roofs. Ice damming is caused by melting of snow cover at higher portions of the roof and subsequent refreezing at lower portions of the roof (frequently those not over heated spaces, such as at the eaves). This is associated with upper portions of the roof deck attaining temperatures above freezing when ambient temperature is below freezing. Prevention measures may be broadly classified as: (1) limiting heat loss from the conditioned space to the roof space, and (2) cooling the bottom of the roof deck by ventilation. It is often considered prudent to assume that ice dams may form despite preventive measures, and thus to provide for measures that would limit or prevent leakage if ice dams form. Water barrier flashing sheets that extend far enough up slope to prevent dammed water from leaking into the roof are commonly used for this purpose.

9.6.1.1 Exfiltration, which can transfer heat from the conditioned space to the roof space, bypassing the ceiling insulation has in some cases been identified as a significant factor in ice dam formation. When ice dams form on buildings which have substantial levels of attic insulation, it may be wise to suspect that air leakage is playing a role.

9.7 *Incompatible materials*

9.7.1 Consideration must be given to compatibility of adjacent materials. An example of compatibility is that of sealants with substrates. Another example is compatibility of mortars with masonry units. When questions concerning material compatibility arise, testing of a planned constructions is recommended. The testing protocol may be for an accelerated test procedure. ASTM Standard Practice E 632 addresses development of accelerated test procedures. In many cases however, time and cost constraints do not allow for testing of planned constructions. In these cases designers usually have little option other than to rely on their own knowledge and experience, the experiences of others, and information from material manufacturers. Knowledge of the degradation mechanisms of different materials may be helpful in predicting whether compatibility problems are relatively likely or unlikely.

9.8 *Accumulation of vaporized and condensed rainwater in walls*

9.8.1 Some cladding systems on exterior walls, most notably some masonry cladding systems have the potential to absorb large quantities of rain water or melt water from snow. If exposed to large quantfies of liquid water they may be expected to absorb appreciable quantities. At the point in time that absorption takes place, the cladding system may not necessarily show indication of damage, and there may not be any indication of water leakage through the wall. However, if the cladding system is exposed to solar radiation while wet, it will be heated, and the resulting vapor pressure differential from the cladding system to the inner portions of the wall may reach extremely high levels. Air conditioning the building interior may be expected to increase the vapor pressure differential between the cladding system and the interior surfaces of the wall. Appreciable accumulation of water vaporized by the sun from the cladding system may then condense within the wall. This may result in corrosion or decay of metal or wood-based components respectively within the wall. It may also result in mold growth on interior finishes of sufficient extent to require their replacement. The degree of moisture accumulation within the wall due to solar-induced evaporation from wet claddings is usually greater if an interior vapor retarder is present. Depending on air leakage characteristics of the building and the presence of air pressure differentials, infiltrating air may become saturated as it infiltrates past the wet solar heated cladding, and cause subsequent condensation within outer walls or even within interior partition walls.

9.8.2 Numerous things, singly or in combination, can be done to limit the degree to which water may accumulate in walls via the mechanisms outlined in 9.8.1. Cladding materials that are less absorptive of liquid water may be used. The absorptive properties of cladding materials can be modified by use of water repellent sealers. It may be possible to limit the exposure of the wall to large quantities of water by any of the means discussed in 8.2 and its subsections. Assuring that the cladding is not exposed to roof runoff is usually a simple and very effective measure. Design of the wall system so as to allow for dissipation of water from the cladding system by drainage and/or ventilation can drastically reduce the length of time that the cladding remains wet. If the building is constructed in a warm climate, use of a vapor retarder behind the cladding material may be justified. See 8.6 and 9.3.2 for guidance on the use and placement of vapor retarders. As indicated in 8.6.1.1, use of numerical modeling to identify how the wall will perform with a proposed vapor retarder is desirable.

## 10. Suggested Field Check Lists

10.1 The lists give some items to be considered during and after construction. The lists are intended for use after the building design has been completed. The assumption is that the building design has been determined as appropriate for the site, climate, and intended use by one or more of the design methods mentioned in 7.1. Items in the list given in 10.5 apply to existing structures in which moisture problems may exist. Obviously the inclusion of all known conditions that might indicate moisture problems would require an excessively lengthy document. The items listed should serve as guides to development of checklists, which may vary with specific building design and climate.

10.2 The owner or manager should keep a record book of building use, maintenance and of performance problems and responses to those problems. This will aid in explanation of future performances. Evaluations of the conditions of building components and their performances are usually hampered by no or few records of events that affected the building or of maintenance or repair work done to the building. Records of changes of occupancy characteristics and when they occurred are essential for realistic evaluations of performance of materials, components, or the construction as a whole.

10.3 *During construction*

10.3.1 Assure that the builder understands design intent with regard to moisture management. This most commonly concerns installation details that concern management of rainwater. When details given by designer are not practically executable, resolve problems via communication with designer.

10.3.2 Check that components meet specifications and design intent. If they do not, consult with designer. Either do not use these components, or modify their installation so as to meet design intent.

10.3.3 Check moisture content of materials during construction. Do not use wet materials in locations where design will not permit rapid dissipation of moisture. Alternatively, modify construction schedule or on-site practices to allow drying.

10.3.4 Check workmanship: below-grade drainage (where specified), capillary breaks, vapor retarders, air retarders, flashing, window installation, ductwork.

10.4 *At commissioning*

10.4.1 Check for management of precipitation: proper grading at foundation, proper pitch of guttering and termination of downspouts, inspection of flashings and sealant applications.

10.4.2 Check for pressure balancing of air handling systems.

10.4.3 Determine that building operation for first year of occupancy is adequately planned. This may be necessary for dissipation of moisture from wet building materials.

10.5 *In Service*

10.5.1 Promptly note any unexpected performance. This includes, but is not limited to leaks, window fogging, and indoor mold growth. Improper drafting of combustion appliances requires immediate attention; it is a potential life-safety hazard as well as a potential source of moisture problems.

10.5.2 Note carefully any treatments for problems and dates.

10.5.3 Note any changes in occupancy characteristics.

10.5.4 Keep note of maintenance performed on the building, including painting and sealant maintenance.

10.5.5 Keep note of renovations or modifications made to the building, or changes in landscaping. Landscaping changes, including those on adjacent properties, may affect site drainage.

10.5.6 Periodically (seasonally) note and record indoor humidity.

10.5.7 Keep note of use of unvented combustion appliances. Keep use of such appliances within usual and customary limits.

10.5.8 Check condition of windows and caulk seals yearly.

10.5.9 Check gutters and downspouts and clear blockages as need. The needed frequency will depend upon proximity of trees to the building. Do not overlook the possibility of bird nests causing blockages.

10.5.10 Where the roof space is accessible, check for roof leaks yearly, especially at roof penetrations.

10.5.11 Check for plumbing leaks twice yearly. In particular look for leaks associated with sinks, shower enclosures, and bathtubs.

10.5.12 Keep note of use of landscaping irrigation. Do not allow irrigation spray to contact the building unless it was designed and built to accommodate such wetting.

## 11. Keywords

11.1 buildings; moisture induced; water induced damage

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