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CONDENSATION CONTROL MECHANISMS IN EXTERIOR WALL ASSEMBLIES

by

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RCI 21st International Convention & Trade Show
March 23-28, 2006
Phoenix, Arizona

Summary

Included in this article are:

- ✓ Descriptions of exterior wall assemblies and what can be done to provide condensation control mechanisms.
- ✓ An overview of scientific principles and regional variations of humidity, condensation and water vapor from multiple sources, to allow the designer to be mindful of where in the wall assembly problems normally occur, and
- ✓ A discussion of the transmission of humidity, condensation and water vapor through exterior walls, roofs, the other components of the building envelope and other building materials.
- ✓ A discussion on confined space, ventilation, history of its inception in the building code, current International Building Code (IBC) requirements and the weakness of the existing code.

Included are scientific principles of moisture phase change, moisture diffusion, vapor barriers and how to read and interpret psychometric tables and charts.

This discussion includes typical sources of moisture, both intended and unintended, air barriers or lack thereof and their impacts on building components. Also discussed is the state of construction today with impacts from changes in materials, designs, assemblies and construction practices. The article includes heating and cooling climates in North America and how condensation control mechanisms vary in the different climates.

1. <u>Understanding the Sources and Causes of Moisture and Condensation</u>

Humidity, Moisture, Water Vapor and Condensation

Condensation can become trapped and collect within exterior wall assemblies. Sources of moisture for condensation include humidity or water vapor that can occur naturally from climatic conditions; and moisture or water vapor that comes from the occupancy load, and interior building amenities such as kitchens, spas, rest rooms, showers, indoor pools or other amenities.

In order to help address the impacts of condensation, we will therefore look at the causes and sources of condensation, and describe how and where vapor transmission occurs through interior and exterior walls. By way of comparison, there will be a brief discussion of how water vapor transmission and moisture condensation occurs in roof assemblies. Finally we will present protocols for remediation of these conditions through good design, vapor barriers and ventilation.

Note that it is natural for water in all its forms to enter a building and its components. From our perspective as designers, we have found that one step in preventing condensation from occurring or collecting, is to block as much vapor or liquid water intrusion as possible; and where they can not be blocked, to design a way for the various forms of water to breathe or weep through the building components.

Because lack of appropriate design or a construction defect can cause a system or portion of the system to not perform properly, timely inspection during construction can prevent a significant amount of future damage. We have also found that once a building is placed in operation, that good design is augmented by periodic inspection and maintenance that eliminates or controls sources of moisture and condensation. Included at the end of this article is a description of what to look for in existing buildings.

Direct Water Intrusion

The indirect, but related focus of this article is on condensation related to direct water intrusion through and around windows, doors, siding (wood, cement plaster/stucco, veneer, stone, brick, wood, manufactured wood siding and concrete), roofs, decks, lanais, plazas, flashings and below grade waterproofing. Water is known to enter those components from rainwater and from failure of sewage, drainage lines and water service pipes. Once water enters the wall or roof assembly from a leak, in the process of drying or breathing out (or lack thereof) can result in unanticipated condensation and damage.

Foundation of this Article

The information contained in this article is based on:

- ✓ My experience in forensic investigation of building failures for construction defect litigation.
- ✓ Our firm's experience in investigation of design and construction failures.

- ✓ Design of new construction wall assemblies.
- ✓ Peer review of the designs of other professional architects and engineers.
- ✓ Our experience in monitoring new construction and repair projects.
- ✓ Our experience providing maintenance methodologies to our clients.
- ✓ Our review of 2003 IBC requirements for attic ventilation and why it fails to meet sound engineering principles for condensation control for cooling and mixed climates.

2. Understanding the Principles of Water Phases, Relative Humidity, Condensation, Vapor Retarders and Vapor Pressure

Water Can Exist in Three Phases:

- ✓ Ice
- ✓ Liquid, between 32 degrees (freezing) and 212 degrees F (boiling).
- ✓ Gas phase (steam) from boiling, or gas phase (water vapor) from evaporation, when the temperature is below boiling point. When cooled, water vapor will lose energy and return to liquid, i.e., it will *condense.*

The Impact of Relative Humidity on Condensation

Relative humidity is the amount of water in its gaseous phase that can be contained within a given volume of air, as a function of the air's temperature:

- ✓ Warm air holds more moisture than cold air because the molecules of hotter air are farther apart, leaving more room for water vapor
- ✓ Humid climates in the United States have many sources of humidity, both external and internal.
- ✓ External to the building are water sources in lakes, ponds, oceans, lagoons, etc.
- ✓ Internally, the physical amenities and occupancy load of the building provide moisture sources.

Relative humidity is expressed as a percentage: 100% humidity means that the air is saturated at that temperature. The geographical variations in ambient humidity can be seen in the following chart:

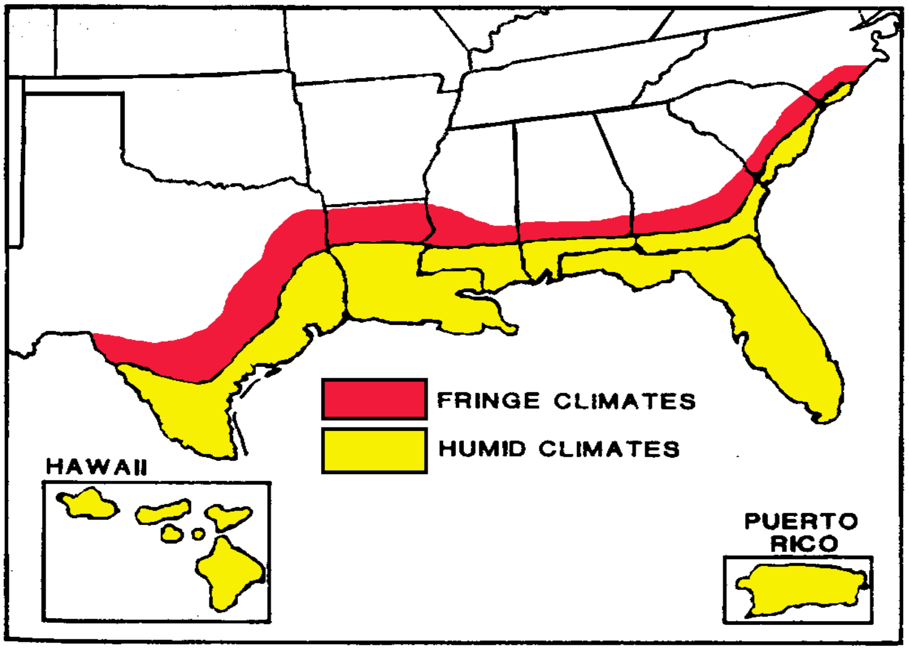

Figure 1 Regional Humidity Variation

When Water Vapor Condenses

When air containing moisture cools to a certain temperature or below, some of the moisture is released – it condenses into liquid water. The temperature at which this occurs is the "dew point."

This temperature is relatively low in the more dry areas of the United States, including the Southwest. This temperature is relatively high in the more humid areas of the United States, including Hawaii and the South Eastern regions. Condensation occurs when humid air meets cold surfaces such as walls, chilled water lines, even insulation, above or near pools.

The following table from the National Roofing Contractors Association shows the dew point temperature at certain relative humidity points compared to the dry bulb (typical thermometer) temperatures. To determine a dew point temperature, align the two axes of the following chart. For example, at 50 degrees F and at 50 % humidity, the dew point temperature is 33 degrees F. Thus, with no other changes, water will condense at 33 degrees F.

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The NRCA Roofing and Waterproofing Manual—Fifth Edition

APPENDIX 4: PSYCHROMETRIC TABLE

Dew-Point Temperature (°F)															
Relative Humidity	Design Dry Bulb (Interior) Temperature (°F)														
	32°F	35°F	40°F	45°F	50°F	55°F	60°F	65°F	70°F	75°F	80°F	85°F	90°F	95°F	100°F
100%	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100
90%	30	33	37	42	47	52	57	62	67	72	77	82	87	92	97
80%	27	30	34	39	44	49	54	58	64	68	73	78	83	88	93
70%	24	27	31	36	40	45	50	55	60	64	69	74	79	84	88
60%	20	24	28	32	36	41	46	51	56	60	65	69	74	79	83
50%	16	20	24	28	33	38	41	46	50	55	60	64	69	73	78
40%	12	15	18	23	27	31	35	40	45	49	53	58	62	67	71
30%	8	10	14	16	21	25	29	33	37	42	46	50	54	59	62
20%	6	7	8	9	13	16	20	24	28	31	35	40	43	48	52
10%	4	4	5	5	6	8	9	10	13	17	20	24	27	30	34
Adapted from ASHRAE Psychrometric Chart, *1993 ASHRAE Fundamentals Handbook.*															

Figure 2 Dew Point Calculations

The following chart from ASTM's *Moisture Control in Buildings*, by Heinz R. Trechsel also shows the corresponding wet bulb temperatures at which the dew point occurs. Wet bulb temperature is measured using a standard mercury-in-glass thermometer, with the thermometer wrapped in muslin (cloth), which is kept wet. The evaporation of water has a cooling effect, such that that the temperature indicated by that bulb is less than the temperature indicated by a dry-bulb, normal unmodified thermometer.

To read this chart, note the point where the wet bulb temperature intersects the 100% RH (Relative Humidity) line. At 12.5 degrees Celsius (55.5 degrees Fahrenheit), on the wet bulb thermometer, the corresponding dry bulb temperature is 25 degrees Celsius (77 degrees Fahrenheit). Thus, with no other changes, water will condense at 12.5 degrees Celsius, wet bulb temperature, in this example.

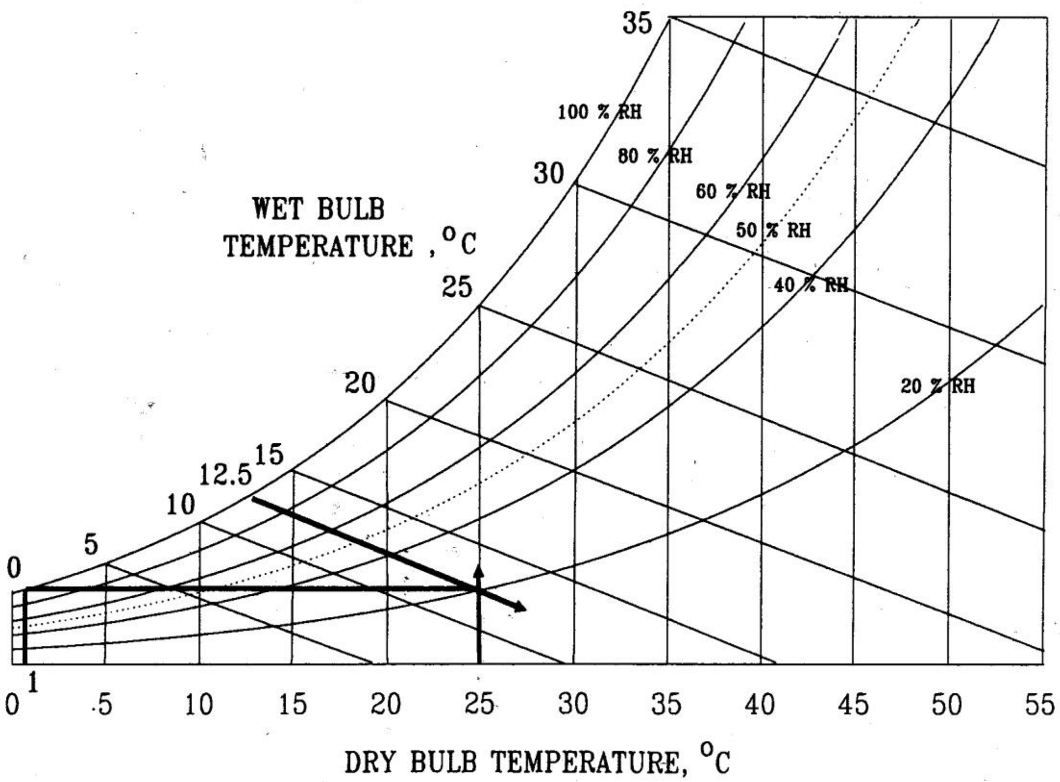

FIG. A4—Calculation of relative humidity and dew point temperature from psychrometric measurements.

Figure 3 Dew Point Calculations Using a Wet Bulb

Water Vapor Pressure

Gases, including water vapor, exert pressures. The amount of pressure that water vapor exerts is a function of temperature and relative humidity. Water vapor will flow from the place of higher vapor pressure, to the place where the vapor pressure is lower.

In most of the United States, this occurs in two typical conditions:

- ✓ Through exterior walls (outside high vapor pressure, inside low vapor pressure)
- ✓ Through a bathroom or other wet environment to another room with a cooler and drier environment such as a bedroom, and eventually to an exterior wall.

Temperature plays a big role in the transport of vapor through a material or an exterior wall assembly (and most building assemblies). Higher temperature excites the molecules to a higher state of energy and thus increases the vapor pressure. Water molecules move across from a state of higher energy (high vapor pressure) level to an area of lower vapor pressure or energy level. The driving potential for vapor transport is the difference in vapor pressure across a material or assembly.

Diffusion/permeability
Diffusion is the transmission (or transport) of water vapor through a material. However, some materials allow diffusion to occur more rapidly than others, thus a material's ability to allow diffusion of water vapor is measured by "permeability" and "permeance" Diffusion is the speed of water vapor transmission through a material, induced by the vapor pressure difference between two sides.

Permeance

- ✓ Is based on a given thickness of material
- ✓ Measured in "perm" units per square meter
- ✓ Permeance ratings under 0.5 = vapor retarder

Permeability

- ✓ Is based on a given thickness *range* of material
- ✓ Example, permeability of concrete (as opposed to 1/2" thick sheet rock)
- ✓ Measured in "perm-inch/meter"

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Typical Water Vapor Permeance and Permeability Values[1,2]		
Material	**Permeance (perm)**	**Permeability (perm•in)**
Common roof membrane materials:		
Asphalt (hot applied, 2 lbs/100 ft^2)	0.5	
Asphalt (hot applied, 3.5 lbs/100 ft^2)	0.1	
Built-up membrane (hot applied)	0.0	
No. 15 asphalt felt	1.0	
No. 15 tarred felt	1.0	
Roll roofing (saturated and coated)	0.05	
Common insulation materials:		
Expanded polystyrene insulation		2.0 - 5.8
Extruded polystyrene insulation		1.2
Plastic and metal films and foils:		
Aluminum foil (1 mil)	0.0	
Kraft paper and asphalt laminated, reinforced	0.3	
Polyethylene sheet (4 mil)	0.08	
Polyethylene sheet (6 mil)	0.06	
Other common construction materials:		
Brick masonry (4 in. thick)	0.8	
Concrete (1:2:4 mix)		3.2
Concrete block (with cores, 8 in. thick)	2.4	
Gypsum wall board (plain, 3/8 in. thick)	50	
Hardboard (standard, 1/8 in. thick)	11	
Metal roof deck (not considering laps and joints)	0.0	
Plaster on metal lath	15	
Plaster on wood lath	11	
Plywood (Douglas fir, exterior glue, 1/4 in. thick)	0.7	
Plywood (Douglas fir, interior glue, 1/4 in. thick)	1.9	
Wood, sugar pine		0.4 - 5.4

Figure 4 - Permeance and permeability of typical building materials – the higher the number, the more moisture that passes through

Understanding the Other Physical Forces in Play

There are numerous forces that cause moisture to move through a building or through an exterior wall assembly, or collect:

- ✓ Air movement is one of the most significant transport mechanisms for moisture movement in buildings, more so than diffusion through walls.
- ✓ Pressure differential between outside and inside caused by wind and air leakage or openings like doors and windows is another significant mechanism.
- ✓ Use of Vinyl Wall paper on the interior face of an exterior wall in cooling climates such as Hawaii or Florida can create an unwanted mechanism for condensation, at the interior face of an exterior wall assembly.

The essential point made about exterior wall condensation control mechanisms is that not only are control mechanisms essential, so too is an understanding of the fundamental qualities of the building materials selected.

3. Condensation and Vapor Barriers

To control the way condensation can collect in an exterior wall assembly, it should be noted that residential buildings generate moisture from many internal sources such as, cooking, laundry, showers, etc. Non-residential buildings generate moisture from some of the same sources, plus process piping, food preparation areas, interior plants, interior fountains and heavy occupancy loads.

Warm humid air can easily move through sheet rock and insulation and condense within the wall cavity as they reach the cold outer skin of the building.

Traditional design guidelines require vapor barriers of the exterior walls, in certain parts of the country where the mean average January temperature is below 40 degrees Fahrenheit. Note regional variations in temperature:

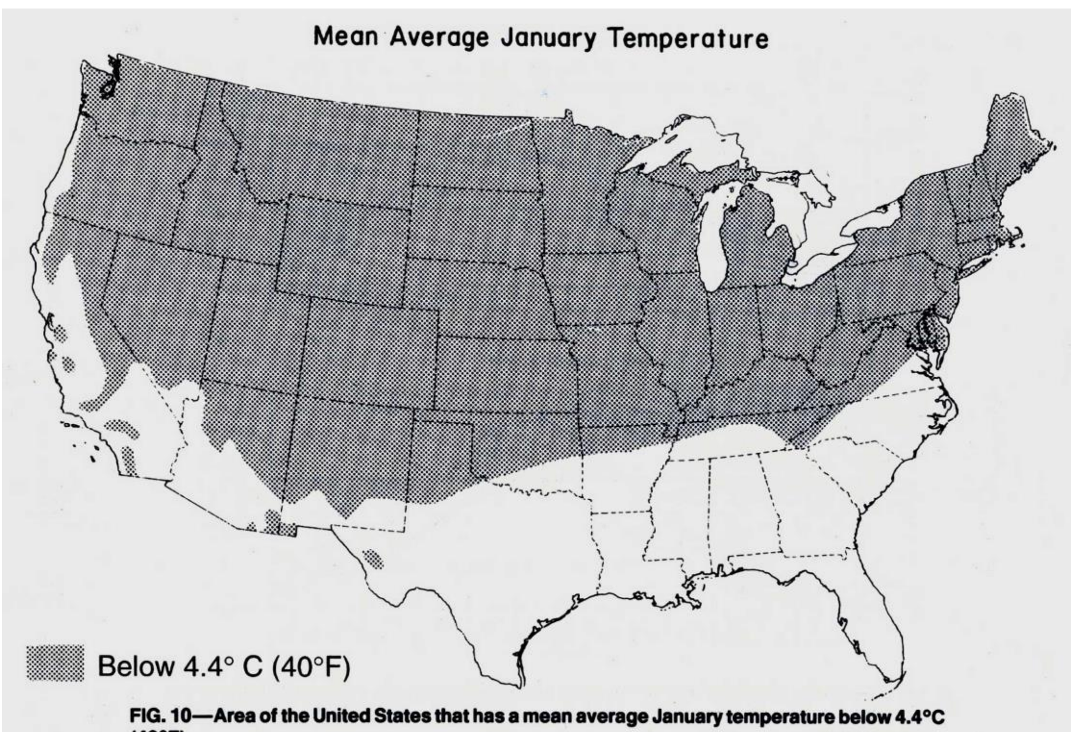

FIG. 10—Area of the United States that has a mean average January temperature below 4.4°C (40°F).

Figure 5 Regional Variation in January Temperatures
Vapor Barriers Required Within Shaded Areas

SOURCE: ASTM Text Book on Moisture Control in Buildings

To deal with condensation, guidelines are published by many agencies such as American Society for Testing and Materials (ASTM), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and National Roofing Contractors Association (NRCA). Current building codes leave it up to design professionals to determine the use and design of moisture barriers on exterior wall assemblies. Since the traditional guidelines, on when and where to use moisture barriers, are changing due to changes in construction methodologies, this is an area that we foresee a lot of mistakes being made by designers and contractors, requiring designers to take special care in applying the guidelines.

There as been a large escalation in condensation related issues and claims resulting from damage caused to walls, exterior siding, exterior sheathing, roof decks and sheathing, and framing members. For example, many class action law suits have been field filed against hardboard siding manufacturers. Hardboard siding is very susceptible to moisture damage caused by condensation and most siding manufacturers require the builder to use a vapor barrier on the inner faces of the exterior walls to prevent this type of damage. This vapor barrier can be expensive to install and is frequently omitted by builders, and often not even shown on the drawings by design professionals.

A new law in California, Senate Bill 800 for residential construction, defines "Designed Moisture Barrier" to mean an installed moisture barrier specified in the plans and specifications, contract documents, or manufacturer's recommendations. As such, all hardboard siding projects may require the addition of a vapor barrier to meet the requirements of this law, even through the building code does not directly require it, or it may be convenient during construction to omit it.

Similarly, due to cost and availability, OSB sheathing is quickly replacing plywood as the exterior wall sheathing material. While OSB is strong, it is significantly more susceptible to moisture damage due to condensation than plywood.

4. Where Condensation Occurs in a Typical Exterior Wall Assembly

The detail below shows a typical exterior wall assembly with exterior cladding, interior sheet rock and vinyl wall covering. The ambient air temperature is 86 degrees F and the dew point is 83 degrees F, due to a relative humidity of 90%.

The temperature within the wall cavity is lower than the ambient air, but as the temperature drops within the cavity due to meeting conditioned air, condensation occurs.

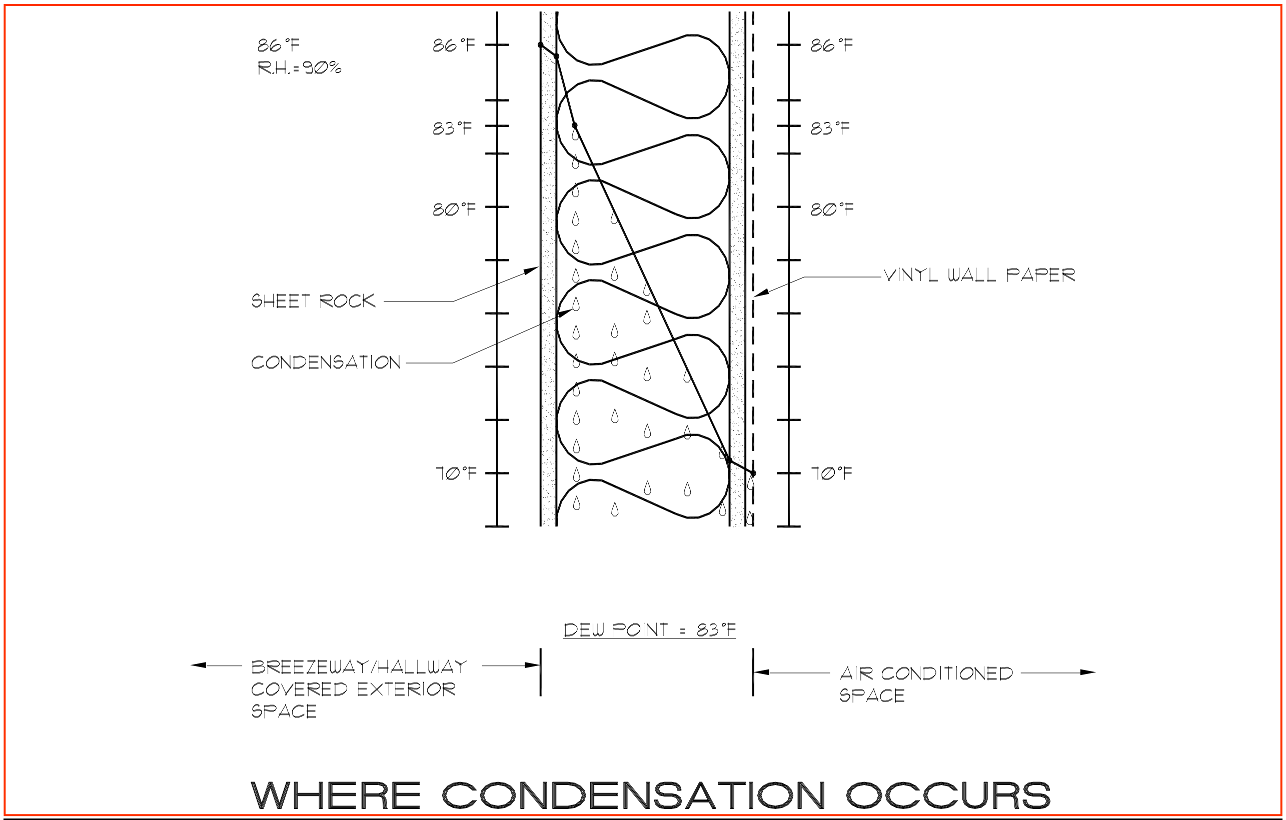

Figure 6 Where Condensation Occurs in a Typical Exterior Wall Assembly
Source: Allana Buick & Bers, Inc.

The condensation control mechanism considerations that should be included in the design, include:

- ✓ Installation of a vapor barrier in the proper location of the wall assembly, on the appropriate side - pay attention to the local climate, because where the vapor barrier is installed in the assembly can vary by geographical location.
- ✓ Numerous types of vapor barriers exist on the market, again it will vary by location.

- ✓ Some climates will call for venting of the wall and roof assembly, some will require only a vapor barrier and no venting.
- ✓ Vinyl wall paper is especially problematic in some climates, including Hawaii and the Southeastern United States, where condensation, leading to mold will occur behind the wall paper.

5. Overall Building Design and Construction Issues and Their Implications on Condensation in The Exterior Wall Assembly

The Secret to Good Design is the Approach of "Belt and Suspenders"
Most designers will provide only what they consider a first line of defense against condensation of all types, and especially condensation in exterior wall assemblies. We have found that the best way to protect our clients is to provide what should be called a "sustainable" building design with proper back-ups to the back-ups for prevention of moisture and vapor penetration, and condensation. We call this method the belt and suspenders approach to providing well designed water tight buildings that also properly handle condensation issues.

Properly designed, the exterior wall assembly of a building should be able to adapt to changes in operating conditions, weather, occupancies, maintenance and use. Buildings should be able to be operated for long periods of time with minimal intervention of trained personnel. It is also our belief that during the first ten years of life of any building, that very little maintenance of building components should be required. It should not be necessary for example, for sealants and caulking to be replaced in that first ten years.

The "Perfect Storm" of Building Problems
We are all familiar with the book and movie, ***The Perfect Storm***, a story of the fishing boat "Andrea Gail" that left Gloucester, Massachusetts in the fall of 1991 only to run into the convergence of three weather patterns, producing 100 foot waves that likely sank the boat.

In the building industry over the last 20 years we have seen our own "Perfect Storm" of building problems: work force changes, poor construction practices, higher insulation requirements, air tight buildings, more manufactured products, more amenities and architectural features, all of which, compounded by design defects, have led to an ever increasing number of building defects and moisture accumulation.

Vapor Barriers
Buildings constructed since the first energy crises of the early to mid 1970's are more air tight, to avoid the loss of conditioned air to the outside, much of which in older designs, was vented through the exterior walls. Newer buildings are also now well insulated in the walls, often with fiberglass batt insulation.

HVAC systems are designed to receive the minimum amount of outside air, in order to reduce the amount of air that is heated or cooled. The negative impact of buildings being more air tight is that liquid water accumulated in a wall or roof assembly can only dry through diffusion, as opposed to evaporation, thereby taking more time to dry. In moderate climates like California, air tight construction is a hindrance to evaporation of accumulated water in wall and roof systems.

Vapor barriers, properly installed, again being mindful of the climate, will prevent moisture from condensing and accumulating where it could create damage.

Insulation
Older buildings were not air tight, and also did not have insulation to absorb water or condensation. We have seen many older, wood framed buildings that had poorly built siding or stucco façade that had copious amount of incidental water intrusion or condensation yet had very limited damage due to the fact that there was air leakage and water did not get absorbed by insulation.

Wood and Manufactured Wood Products
Wood in older residential construction tends to be from old growth forests, with tighter grains. Newer wood is rapid growth, with wide grains, making it more susceptible to the damage caused by moisture in energy tight buildings. Worst yet is hardboard, OSB, Paralam and other engineered wood products that have far lower tolerance for water.

Work Force and Its Ability to Properly Construct Exterior Wall Assemblies
There has been a significant change in the work force, including its ability to be able to perform, complicated construction or plan for integration of complex building assemblies that are installed later in the sequence. This has created a real decline in the quality of the work force and quality of construction, as contractors and subcontractors involved with construction, especially building envelope construction, find it difficult to locate sufficient personnel with the type and extent of training (knowledge, skills, and abilities) that contractors in the industry have had in the past. It is our opinion that this is due partially to the downsizing of union membership beginning in the early 1980's and continuing

today, resulting in fewer apprentices that eventually progress to journeyman or master level craftspeople.

Unions had served as feeder programs for training future contractors by providing accredited training programs through formal apprenticeship programs. With the reduction of these programs, today's contractors are less fortunate when it comes to meeting their training needs. These changes have also had a tremendous effect in the ability to find skilled workers, without providing in-house training programs. This has also led to workers that have less of an understanding of how all the trades work together, coming at the same time that there is an ever increasing need for understanding of how to build what are now very complicated buildings.

Specifically, rather than a comprehensive knowledge of all aspects of the building envelope industry and specifically the exterior wall assemblies (i.e., plaster, lath, drywall, exterior insulation finish system (EIFS), metal-stud-stud framing, wood framing fire-proofing, insulation and specialty), today's worker tends to be limited in his or her breadth of knowledge. This lack of standards for the building envelope industry creates additional problems in the trade because there is a lack of specific standards that can be used as a basis for competency certification at the contractor level.

Lack of Skilled Work Force in Many Geographical Areas
Because there has been a lack of training programs, this has led to a lack of a sizable skilled work force in many geographical areas. It has been our experience that some construction trades are worse off than others.

Poor Construction Practices
Poor construction practices and lack of construction monitoring has lead to construction defects. This has been especially compounded by

- ✓ Quick construction, improper attention to sequencing low ball pricing, subcontractor squeeze, lack of qualified contractors and workers.
- ✓ Possible lack of accountability by general contractors and owners,
- ✓ Lack of on site monitoring and inspection leads to poor construction

Today the methods for the building shell construction have grown in number, traditional building envelope materials are being used in more, new and varied applications and for many more purposes, and new technologies such as Exterior Insulation Finish Systems (EIFS), hardboard siding, gypsum sheathing and compact roof assemblies without ventilation are being commonly used. The variation in types of architectural features, to which traditional methods have been applied, has grown tremendously. The more energy efficient buildings are built very air tight which has resulted in tremendous increases in condensation related damage.

Lack of Moisture Control of Building Materials During Construction

Materials that arrive and are stored on site must be dry and mold free in order for the project manager to take possession of the shipment and to install it properly. The responsibility for receiving shipments and keeping them moisture free, at all time, is the responsibility of the contractor. Assuming that the materials arrive in dry condition on site, the contractor needs to take the following actions:

- ✓ Inspect materials on the delivery vehicles to make certain that they arrive with all packaging materials intact. Look for damaged packing and materials
- ✓ Inspect materials as they arrive, documenting and rejecting wet or moldy materials
- ✓ Prepare a temporary set-down or permanent storage area is dry and will remain dry
- ✓ If moldy or otherwise damaged material cannot be returned immediately, provide a quarantine area
- ✓ Educate construction crews in proper techniques of handling materials to maintain dryness
- ✓ Inspect stored materials frequently
- ✓ Inspect materials as they are installed

The American Wall Construction Institute provides the following specific guidance for gypsum board products. We believe that adopting similar practices for other building components would also be beneficial:

> *"Enclosed protection from the weather is required for the storage of all gypsum products. It is important to store materials off the ground to avoid wicking of water from the floor or drying concrete, and to allow ventilation, to avoid condensation. Drying concrete releases nearly 50 gallons of water per yard of concrete during the curing process, which takes more than 30 days. Use risers, skids or dunnage at the site to keep the bottom of materials at least 4 inches off the floor, with clear airflow under the bundle. The materials should rest flat on wood risers spaced no more than*

28 inches apart and no more than 2 inches from the end of the board, to avoid sagging or warping of the boards. Locate stored stocks of gypsum products away from heavy traffic areas on clean and dry floors in the centers of the largest rooms to prevent damage.

Materials that are stored where rain or construction process water could fall on them should be covered with tarpaulins that are heavy enough to withstand any wind or other harsh conditions. While the tarpaulin should be weighted down on top to prevent it from blowing away, it should be tight against the sides of the stack because this can reduce air circulation and hold moisture inside the sheathing. When tarpaulins and other temporary protective measures are used, the materials should be checked frequently for evidence of moisture damage or mold growth."

The above description is just one example of the attention to detail that should be provided on a construction site in order to prevent moisture from accumulating in building materials during construction. The AWCI also recommends these procedures:

- ✓ Manufacturer role. The manufacturer of materials is responsible for quality control during the manufacture, baking and curing periods. The materials needs to be kept dry and wrapped during shipment.
- ✓ Supplier and distributor role. Wall and ceiling materials need to be kept dry during shipment, and should be shipped to the site only when needed.
- ✓ Transporter's role. The carrier needs to keep the material dry at all times and deliver the material to a responsible party on site.
- ✓ On site monitor's role. The monitor, typically hired as a third party by the owner, is responsible for assuring that materials arrive dry, are stored that way and are installed dry. Our construction monitors are trained to reject materials that arrive wet, and we can and do reject materials that are installed containing moisture.
- ✓ Protection of Building. Although somewhat obvious, the AWCI also recommends careful attention being paid to keeping the building dry during all phases of construction.
- ✓ Proper sequencing and coordination. The need for proper sequencing and coordination of the various trade contractors cannot be over emphasized. Installing interior finishes, for example, prior to complete

dried in states will like lead to moisture and mold related problems as will not properly commissioning the building systems.

- ✓ Proper installation, maintenance, test and balance of the HVAC system. An allegation that often appears in mold exposure cases is that the contractor and/mechanical subcontractor failed to properly install, maintain, test and balance the HVAC system at the project.
- ✓ Documentation. AWCI recommends that field supervisory personnel document, through written daily reports, photographs and other means, the work in progress, including construction practices as well as climatic conditions. Our monitors provide daily check lists and project summaries to the client for this purpose.

Construction Monitoring

Studies by the Federal Government, a major association of design professions, and a major professional liability insurer show that full-time construction observation by the design professional of record is the best defense against problems during and after construction; that the absence of this service can be associated with numerous problems that have resulted in claims and losses due to condensation.

Manufactured Products

More manufactured products of all types= food sources for mold. There are numerous sources in today's buildings to satisfy the nutritional needs of mold, fungi and other life forms. These sources include materials containing cellulose, such as blown in cellulose insulation, gypsum wall board ("sheet rock"), exterior wood siding and exterior manufacturing composite siding, wood paneling, plywood, Oriented Strand Board (OSB), pre-cast composite panels, ceiling tiles, fabrics and carpet, draperies, wall paper, paper backing on fiberglass insulation, upholstered furniture, fiberglass lined air ducts, chilled water line insulation, wood shingles and others.

Modern manufactured building products with added binders, resins and fillers are more susceptible to mold growth than natural products, as they lack naturally occurring resisters such as antimicrobials.

This complexity of modern building materials contrasts with older homes and multi-family housing unit construction that may contain old growth hardwood or other natural material. These older materials can contain naturally occurring chemicals that inhibit the growth of mold and fungi.

Among the types of building materials we find, that are more susceptible to damage from condensation include:

- ✓ OSB
- ✓ Hardboard siding
- ✓ Manufactured wood products
- ✓ Gypsum board
- ✓ Paper
- ✓ Wood
- ✓ Organic glues, oxygen and water

More Amenities and Features

More architecture features, embellishments, amenities and aesthetic enhancements in the last ten years are more difficult to design and build and can create far more compounded problems when not done properly. In an attempt to make properties more pleasing, that is marketable, and with the advent of computer aided drafting, architects are in a better position to create more complicated building styles, with more types of materials and more difficulty in construction.

The inclusion in most building design of many more water and water vapor sources, such as more wet areas, showers, kitchens, steam room, wet crawl space, etc.

Design Issues

Inherent design defects include:

- ✓ Lack of understanding of how to integrate and details of different building envelope components, especially in the complicated exterior wall assembly.
- ✓ Lack of constructability of the design, due to lack of understanding or improper sequencing.
- ✓ Cathedral ceilings with compact roof assembly.
- ✓ Lack of properly displayed and drawn details.
- ✓ Building envelope and roof design typically happens at the end of the job, when the design and construction budget is tight.

Vapor retarders have been overlooked by design professionals and builders alike. Today's buildings are much more air tight, insulated and prone to condensation which can cause just as much rot, mold and damage to building components as water intrusion from rain.

6. Typical Locations Where Condensation Occurs in Other Exterior Building Assemblies

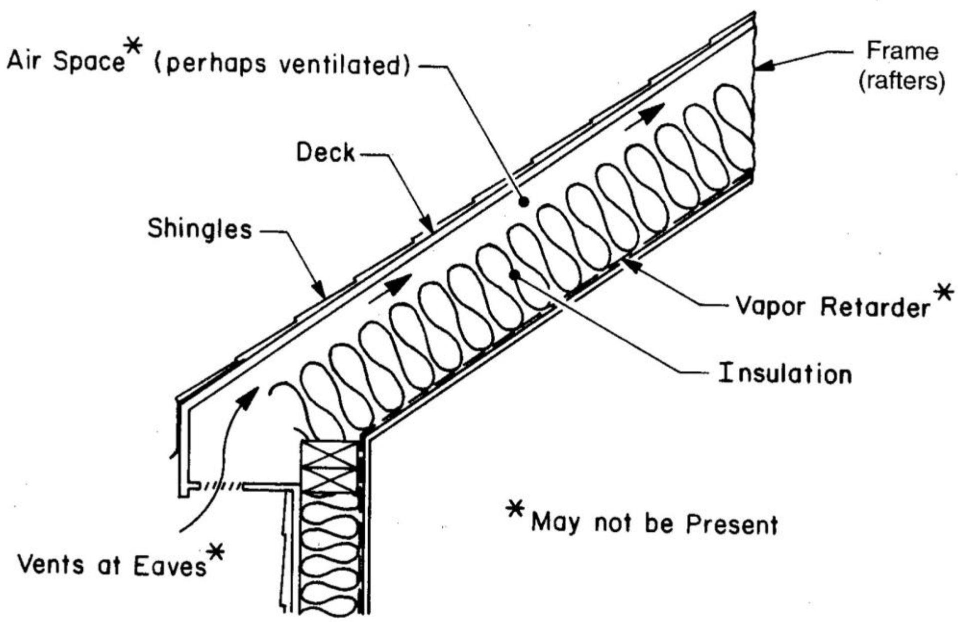

Figure 7 Typical Compact Roof Assembly
Source: *ASTM Text Book on Moisture Control in Buildings*

Fundamentally, it is my opinion that the current versions of the IBC 2001 and 2003 and older versions of UBC do not address adequately address the issue of condensation control mechanisms. The above graphic shows this for sloped roof compact assemblies. The graphic below Fig 8 shows this for flat roofs. IBC 2003, section 1203 VENTILATION states, Attic spaces, enclosed rafter spaces.....shall have a net free ventilating area shall not be less than 1/150.... If a vapor barrier is used (exception) then the requirement for ventilation is reduced to 1/300. In both cases, 50% of the ventilation shall be located in the upper portion of the roof, at least 3 feet above eave or cornice vents.

In my opinion, there are two things wrong with this requirement. First, Code does not distinguish between low sloped and steep sloped assemblies; however it requires that the upper vent be located 3' above the eave vent. On low sloped roof assembly, there may not be a 3' elevation change between the eave and ridge. Secondly, in cooling climates, warm humid air between rafter spaces above insulation will likely condense on cool, air-conditioned ceiling lid, or worse vapor barrier under the insulation on the cool side of the roof assembly on Fig 7 or 8.

While the building code section applies to roofs, it is our firm's opinion that some of this thinking could conceivably create design misunderstandings, when applied to exterior wall assemblies.

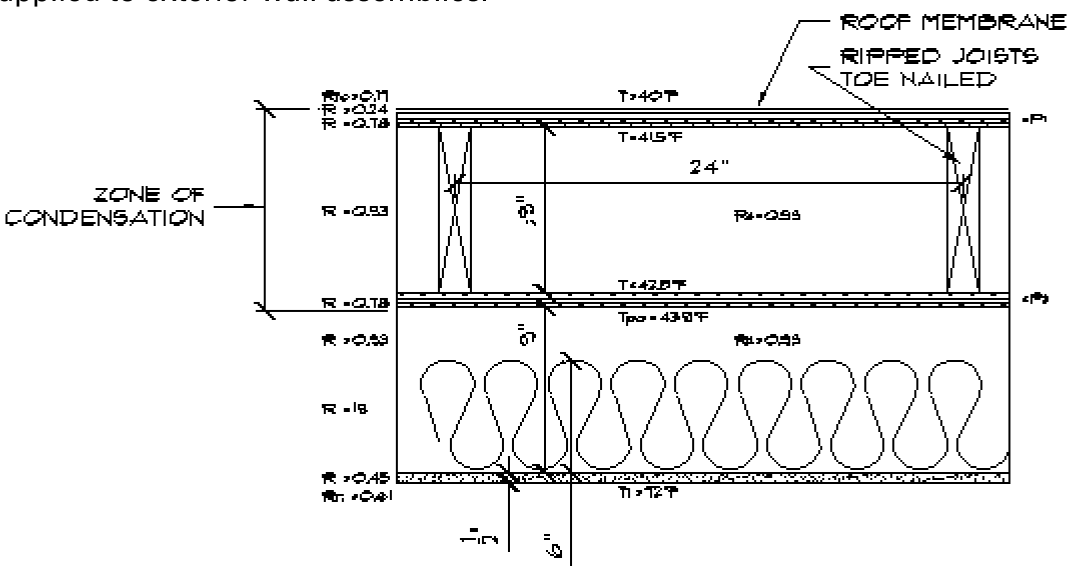

Figure 8 Typical Flat Roof Compact Roof Assembly
Source: Allana Buick & Bers, Inc.

7. Intended and Unintended Moisture, Vapor and Water Barriers

As described in this paper, both the geographical area where the building is located and the actual design have a direct impact on the ability of exterior wall assembly construction to withstand the effects of condensation, water intrusion and moisture. The following questions should be answered and addressed during design of all exterior building assemblies including walls:

- ✓ Where in the building does condensation normally occur?
- ✓ Where can moisture accumulate?
- ✓ Where can it be difficult for moisture to be diffused?

Exterior wall assemblies prone to failure:

- ✓ Exterior wall assemblies that are not properly designed.
- ✓ Windows which are improperly flashed or installed.
- ✓ Siding which was improperly manufactured or installed.
- ✓ Through wall flashings that were improperly designed or installed.
- ✓ Roof assemblies that were improperly designed, poorly constructed, or are past their lifetime causing leaks.
- ✓ Drain lines contained within walls, where the pipes have failed because of poor design, improper installation, ground subsidence, or, because of the improper use and dumping of chemicals.
- ✓ Condensation on interior face of concrete walls due to lack of vapor barrier.
- ✓ Chilled water pipe insulation failures, causing condensation and resultant mold growth.

8. Diagnosing Condensation Problems In Existing Exterior Wall Assemblies, in Order to Implement the Correct Rehabilitation and Repair Solutions

Our experience includes design of new construction, as well as forensic investigation and design for rehabilitation of existing exterior wall assemblies. We have found the following to be appropriate ways of looking for problems in existing exterior wall assemblies:

- ✓ Look for evidence of stains near the windows, and other wall locations.
- ✓ Look for evidence of stains near the base of walls, particularly under carpet, at the tack strips.
- ✓ Behind furred concrete walls, evidence of condensation may be hidden.
- ✓ Look for possible evidence of failed chilled water insulation within wall assemblies.
- ✓ On site maintenance staff is the greatest source of gathering evidence, although they typically know where to look for roof leaks at the ceiling, but are somewhat limited in knowing how to assess exterior wall problems.

- ✓ Maintenance staff should not paint over leaks, should take photos and map the leak locations, before the repairs are made.

Tools That Can Effectively Analyze the Causes and Location of Wall Condensation and Other Moisture in Existing Exterior Wall Assemblies

- ✓ Sampling protocols including random sampling
- ✓ Destructive testing
- ✓ Boroscope
- ✓ Infrared cameras
- ✓ Water testing and leak tests
- ✓ Visual analysis
- ✓ Delmhorst

Evidence of Building Damage

Preventing building damage from condensation is the topic of this article, The types of damage that may be evidence of condensation caused damage, or that may be evidence of damage from other causes include:

- ✓ Wood rot
- ✓ Mildew
- ✓ Fungi growth
- ✓ Rust
- ✓ Efflorescence
- ✓ Paint blistering

Conclusion

Understanding and designing wall and roof assemblies for moisture control and condensation remains a challenge and often elusive goal. One building official, recently commented "There is no science (or engineering) to design of vapor barriers, code required ventilation must be provided and is the only means to prevent condensation in roof assemblies". First published standards for ventilation and condensation control were published by Federal

Housing Administration (FHA) in 1942 which required ventilation of 1/150 for "basementless space" and 1/300 for attic. Today, while construction methodology, roof and wall assemblies, construction materials, and requirement for air tight construction have dramatically changed since 1942, building codes and requirements for ventilation and condensation control design has remained relatively unchanged. In order to properly design for exterior wall condensation control not only requires better understanding of the wall or roof assembly and condensation mechanism, it also requires changes in current building code.