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Forensic Engineering Overview of Effect of Weather Resistive Barriers on Building Envelope Deterioration

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Introduction

Since adoption and widespread implementation of the Model Energy Code promulgated by the Department of Energy and incorporated into most state building codes, there has been widespread experience with deterioration of building envelopes, particularly wood frame building envelopes. Requirements for weather resistive barriers (WRB's) have been added to the major national codes for nearly all applications with multiple significant changes in successive recent editions of the major building codes. Moisture/water related problems have manifested in other types of construction, including masonry, resultant to recent requirements of building codes and unanticipated adverse effects caused by lack of testing and integration between the building code provisions and energy codes. Some of these areas have been reported upon in other papers.

Extensive litigation relating to deterioration of the building envelope is ongoing. Allegations relating to building code defects are nearly always central in these cases, necessitating understanding of the relevant codes and construction practices in the regions and time frames of the construction. A review of the major building codes' provisions as relate to the issues of WRB's in both residential and commercial applications shows the rapid and significant changes in the codes in recent years. The trend in all of the codes has been to require WRB's in more types of construction and/or more layers of WRB's in some types of construction. Increased deterioration and rate of deterioration of the building envelope has paralleled the increased requirements for more applications requiring WRB's and use of plastics in WRB's. These changes in the major national building codes have not had the intended effect of protecting the building envelope. Rather in many cases the increased usage of WRB's as mandated by the major codes is causative of the rapid deterioration of the building envelope. Those practicing in the areas of building envelope need be knowledgeable of the requirements of the codes which relate to the construction and the adverse effects of elements of the codes as relate to deterioration of the building envelope. This paper provides a summary of actual field observations of effects of and performance of groups of weather resistive barriers (WRB's) and vapor retarders based upon invasive investigation of building envelopes extending over

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a period of 15 years and provides general guidance to the major codes intended to provide a basis for the expert to obtain further foundational materials and knowledge needed in these types of cases.

Keywords

Forensic Engineer, Weather Resistive Barrier (WRB), building paper, building envelope, cladding, weep screed, type D kraft paper, Uniform Building Code, (UBC), International Residential Code (IRC), International Building Code (IBC).

Issues at Trial Relating to WRB

The case involved a wood frame residential structure with gable style roof finished on the exterior with hard coat stucco which was approximately 10 years old at the time of the litigation. At several locations around the structure primarily below window locations and roof/wall intersections, the fiberboard sheathing was found to be soft or deteriorated by way of advancing probes through holes drilled through the hardcoat stucco cladding. Expert for the homeowner (plaintiff) argued multiple issues relating to the building code and specifically with respect to the building paper or weather resistive barrier (WRB). First, that the building code in force at the time of construction (1994 Uniform Building Code) required 2 layers of Grade D paper and that the as constructed building was constructed with 2 layers of 15# felt paper and that this was in violation of the 1994 Uniform Building Code section 2506.4. Second, plaintiff argued that the building paper (WRB) was improperly installed at window locations in that the paper was "reverse lapped" at lower window nailing flanges meaning that the paper was not installed behind the lower flanges of the windows but on the exterior side of the flanges and that this was in violation of UBC section 1402.1. Third, plaintiff argued that the exterior openings exposed to the weather shall be flashed in such a manner as to make them weatherproof and that this was in violation of the 1994 Uniform Building Code section 1402.2. The home was constructed with flanged type windows. Fourth, with respect to WRB plaintiff argued that the building was not furnished with weep screed at the base of the stucco and that this was in violation of Uniform Building Code section 2506.5. Although in this case the damaged areas (deteriorated sheathing) were limited and localized primarily below roof/wall intersections, plaintiff argued that the deteriorated areas of sheathing were caused by the alleged code violations noted above even though no deterioration or damage appeared elsewhere on the structure.

Code Requirements for WRB's

Requirements for incorporation of WRB's into the envelope of structures has been rapidly integrated into building codes in the US since inception of the Model Energy Codes and derivatives. The term "Weather Resistive Barrier" is utilized by ASTM. The term is also used in major national codes but varies in different codes and editions of codes with similar terms such as "Water Resistant

Barrier" or "Water Repellant Barrier" also used. The term "Water Proof Paper" appears in versions of the Uniform Dwelling Code. References to ASTM standards used to define WRB's appear in most but not all codes. Therefore, in instances where no ASTM standard appears, interpretation of the meanings of the English terms used above can lead to conflicting views of performance levels implied by such terms. The most common WRB and the one which is still referenced in all of the national codes is 15# Asphalt Saturated Felt paper commonly referred to as tar paper which is made from wood pulp and asphalt ASTM reference D226 type 1. Fifteen pound asphalt felt paper was originally and still used as roof shingle underlayment.

The Uniform Building Code (UBC) through the last edition published in 1997 chapter 14 Exterior Wall Coverings, required one layer of WRB meeting the standard of 15# asphalt saturated felt behind only brick and stone veneer and then only when the 1 inch airspace was filled with grout or mortar. The only other area of construction requiring WRB's through the last edition of the UBC appears in Chapter 25 under "2506.4 Weather-resistive Barriers"; referring to the application behind exterior plaster and specifically as required between exterior lath and wood base sheathing which states "…shall be installed as required in section 1402.1 and when applied over wood base sheathing shall include two layers of Grade D paper". WRB's were not required under any other siding type. In the case under consideration, sheathing consisted of fiberboard which the manufacturer advertised as water-repellent panel sheathing.

The writer testified that UBC section 1402.1 includes certain exceptions including exception no. 4 which states "Over water-repellant panel sheathing". Thus the code in force at the time of construction did not require WRB in this application. This results from the fact that the exception was written at a time when plywood was the common sheathing material but new materials such as fiberboard and OSB were becoming increasingly available. Fiberboard, OSB and Gypsum Board (Builder Board) are all indicated by manufacturers as water repellant panel sheathing, thus not requiring WRB. Thus a conflict appears in the code in this area. Further, the meaning of the wording in the code "wood base sheathing" is disputed. Commentary to the code in the period describes wood base sheathing as plywood. OSB and fiberboard are not mentioned. This is an important consideration as the use of actual wood boards as sheathing is essentially unseen in the past 40 years while virtually all frame construction from the 1960's through the present utilizes OSB, Fiberboard, Plywood, or Gypsum Board for sheathing.

Contained within UBC 1402.1 "Weather-resistive Barriers" are application requirements for WRB which call out minimum vertical joint overlap in paper of 6 inches and minimum 2 inches overlap in horizontal joints. The writer testified that this code provision addresses application of paper against paper and does not address application of paper either overlapping or underlapping at the interface with any other materials such as windows or flashing. No code provision appears which addresses application of paper at the interface with flanged/self flashed windows. The term "reverse lapped" does not appear in any edition of the Uniform Building Code or the International Residential Code or International Building Code.

Contained within UBC 1402.2 "Flashing and Counter-flashing" is the following; "Exterior openings exposed to the weather shall be flashed in such a manner as to make them weatherproof." The first reference to self flashing windows appears in the 2000 edition of the International Residential Code (IRC) section 703.8. The writer testified that the flanged windows utilized in the construction are self flashing and were described as such in the International Residential Code section 703.8. Although IRC 2000 was not the code in force at the time of construction of the building involved in the litigation, it provided authoritative text regarding the self flashing windows. The self flashing windows are an exception to any additional flashing requirements; "1….. except that self flashing windows having a continuous lap of not less than 1-1/8 inches over the sheathing material around the perimeter of the opening, including corners, do not require additional flashing". The flanged windows referenced in the matter are typical of flanged windows commonly utilized in residential construction in this period complete with corner gaskets meet the requirements of self flashing windows and therefore require no additional flashing.

Contained within UBC 2506.5 Application of Metal Plaster Bases is the provision "…A corrosion-resistant weep screed …shall be provided at or below the foundation plate line on all exterior stud walls……and shall be of a type which will allow trapped water to drain to the exterior of the building. The weather-resistive barrier shall lap the attachment flange, and the exterior lath shall cover and terminate on the attachment flange of the screed." The last sentence was added in the 1994 edition of the UBC. This is the only place in the building code which addresses application of WRB against any other artifact. The aspect of application of the WRB over the weep screed was not at issue in the litigation. The writer testified that he has observed no evidence of any adverse effect due to lack of weep screeds and no evidence that water actually drains at the weep screed.

In 2000 the International Building Code and International Residential Code were published replacing the UBC. These codes are the model national codes. In the state of Florida, used here for comparison for a tropical and hurricane area, the uniform state building code was introduced in 2001 replacing a set of regional codes which had been in use for various areas of the state.

Requirements in the regional codes varied. The uniform state code was written for Florida by the International Code Council (ICC) and is based upon the International Building Code. In 2004 Florida introduced separate commercial and residential codes, again written by the ICC and based upon the International Building Code and International Residential Code. This paper will not discuss all of requirements of special hurricane zones which are narrowly defined by distances from the coasts and in some municipalities literally on a street by street basis.

Requirements for WRB's in International Residential Code are set forth in chapter 7 in table 703.4. Note the terminology variation from "Sheathing Paper Required" in the table in the 2000 edition and "Water Resistive Barrier" in the 2006 edition. Note "m" in 2000 edition is essentially the same as that which appeared in the earlier UBC editions with respect to brick and stone veneer, the one inch air space and water repellent-panel sheathing. In the 2006 edition, note "l" provides as similar exception, however, the language was changed. The description of sheathing materials from the 2000 edition "water-repellant sheathing" becomes in 2006 edition "sheathing that performs as a weather-resistive barrier". The author is unaware of any sheathing which is advertised by a manufacturer which claims that the sheathing performs as a weather-resistive barrier. Thus the language in this provision in effect mandates WRB's whether a one inch air space does or doesn't exist over any type sheathing material.

Requirements for WRB's in the International Building Code appear in chapter 14, section 1404.2 Water resistive barrier. A minimum of one layer of No. 15 asphalt felt, complying with ASTM D 226 type 1 felt, shall be attached to the sheathing, with flashing as described in Section 1405.3 in such a manner as to provide a continuous water-resistive barrier behind the exterior wall veneer. In the 2006 edition of the IBC, section 1404.2 Water resistive barrier, the section reads the same as the 2000 edition except that "other approved materials" was added and "…shall be attached to the *studs or* sheathing…" was added. Exterior wall veneer is described as all siding.

Although not required in the International Residential Code (IRC) or International Building Code (IBC) in the majority of construction types in 2000, some states mandated WRB on most types of construction with no evaluation or testing by 2003. By 2006, IRC table 703.4 required WRB's in most types of wood frame construction between sheathing and siding. For example, no WRB was required in the 2000 IRC or by most vinyl siding manufacturers over sheathing but became mandatory in subsequent editions of the IRC.

The history requiring so called high vapor transmission WRB seems to date to the UBC handbook which is intended to provide guidance to users and building officials. The handbook simply states that the high vapor transmission WRB has been found to improve drying of the sheathing and particularly references plywood. There is no reference to any testing. This statement has been taken as the gospel on the subject but is nothing more than anecdotal. We and other researchers have found no basis for the statement and no evidence that any testing, research or modeling was ever performed to support this statement. We find no evidence that any type of field testing or long term actual testing of building envelopes was performed which would support such a broad change in the code. The effect has been to further compound elemental problems introduced with the energy codes with respect to inability of the building envelope to shed excess water/moisture.

Types of Weather Resistive Barriers

Weather resistive barriers are manufactured from two basic types of materials, paper products and plastic/synthetic products with various subgroups resultant to variations in material or performance. Technical requirements for WRB's vary widely and the national codes lack quantitative basis for selection and implementation of WRB's as was shown by Butt (ASTM Vol 2, No10, JAI 12495. The widespread mandatory and rapid use of the materials is not based upon scientific testing or field studies. "Marketing and tradition appear to have played a major role in shaping perceptions of WRB's by both the public and building industry professionals." (Butt, Journal of ASTM International, November/December 2005, Vol. 2, No. 10, Paper JAI12495, "Water Resistance and Vapor Permeance of Weather Resistive Barriers".) Absence of a WRB in vinyl siding applications appears to enhance the drying effect for sheathing.

Paper Based WRB's

Paper products generally are represented by kraft type papers or felt papers and bear various designations as Type A, Type B, Type C, Type D. Further distinction between types of papers relates somewhat to the history of the papers. The common Type I (15# asphalt saturated felt) derives from a materials specification calling out the percentage of felt paper and asphalt as compared with the Grade D so called high vapor transmissive papers (water-vapor permeable) which derive from performance specifications. As a result of deriving from a materials specification, 15# asphalt saturated felts have wide ranges of characteristics with respect to water penetration resistance and vapor transmission rates. Generally the 15# asphalt saturated felt papers have a very high water penetration resistance and relatively low vapor transmission rates with the more "breathable" of the 15# asphalt saturated felt papers having been measured to have vapor transmission rates approximately half the minimum specified for Grade D WRB as defined in the codes. Fifteen pound (15#) asphalt saturated felts typically have vapor transmission rates ranging from approximately 3 – 15 grams per square meter per hour. Although 15# felt papers have been described as typically being made from a combination of primarily paper pulp with rag stock, rag stock is essentially eliminated from the product stream in the United States and thus does not currently appear as an ingredient. Some manufacturers are using fiberglass mat instead of wood pulp for base.

Grade D WRB is defined in the major building codes as having certain primary parameters particularly minimum vapor transmission rate and maximum water penetration resistance. This category of WRB is considered to have a high vapor transmission rate and may be made of any material. The minimum defined parameters put forth in the Uniform Building Code and International Residential/International Building Codes define Grade D paper as having a minimum water penetration resistance of not less than 10 minutes as defined by Federal Specification UU-B-790a. The vapor transmission rate is defined as not less than 35 grams per square meter per hour (per ASTM Federal Specification UU-B-790a). We find no evidence in the literature for any technical basis for determining that any of the parameters have any practical relevance in the field. No testing appears to have been done or published and no field trials published which would show that the defining parameters which appear in the codes have any validity in actual construction. Neither the major building codes nor manufacturers literature contain warnings or recommendations for use in tropical regions as compared with cold regions. The designations for Grade D paper were developed prior to advent of the Model Energy Code and derivatives which now appear in the major model building codes.

No materials weight minimums appear in the code definition for the Grade D category of WRB's as do appear for the 15# asphalt saturated felt paper (tar paper). The "10 minute" code defined kraft papers have been found to be light in weight, thin and have been observed in the field to deteriorate (rot) rapidly in the presence of water. The extremely low water penetration resistance of the 10 minute kraft papers renders them essentially useless with respect to blocking water entry. The papers have high capillarity and retain water causing the wood fibers to rot. The kraft papers have wide ranging characteristics with respect to vapor transmission rate and water penetration resistance. Grade D kraft paper advertised as "60 minute" paper is commonly in use in the north central portion of the US with "10 minute" paper essentially unavailable in the marketplace. The "60 minute" kraft papers are heavier than the "10 minute" kraft papers and have been found to be more durable in the field. However, these papers also have high capillarity and relatively low water penetration resistance and hold water leading to rot of the wood fibers. The "10 minute" rated kraft papers appear to have been in more widespread use in the south and west of the U.S.

Plastic Sheet WRB's

Grade D WRB's are also manufactured from synthetics including commonly polyethylene and polypropylene. These materials are generally flat sheet materials which provide vapor transmission by small holes. As one would expect, as the vapor transmission rate increases, the water penetration resistance decreases. This is simply a function of the porosity of these materials. Synthetic papers are generally made from polypropylene and are generally flat sheet materials with small holes for vapor transmission. Varieties of colors of plastics are found which relate to marketing and trademark identification. Sheet plastic WRB's appear bearing the logos of the builders providing advertising for the builder. Some of the synthetic papers are advertised as meeting the requirements of Grade D designation. The parameters for all papers are determined from unconditioned new material. The sheet plastic materials have been found in the field over certain substrates like OSB and plywood and behind certain siding materials such as cedar to plug up with soluble fractions from the substrate thus altering the materials by reducing the vapor transmission rate. Certain types of plastic materials have been observed to deteriorate and become friable after a period of time in service.

Woven Synthetic WRB's

Another general category of non paper pulp WRB materials are fabricated in open weave type materials from spun polypropylene and have a felt like appearance as compared with flat sheet appearance. This type material has a low water penetration resistance and high vapor transmission rate. The open weave results in low capillarity and thus the materials do not retain water. Multiple benefits in some applications appear to derive from these parameters for which the positive effects in the field in a practical sense are apparent. The materials have high void ratios and hence act as a thermal break. The fibers do not deteriorate in the presence of water.

Vapor Transmission Rate

The theory behind the so called high vapor WRB's is breathe-ability and that increased vapor transmission rate of WRB's will speed drying of building materials. No evidence of actual field testing of structures has been found which would support the adoption of the quantitative parameters found in the code which have remained unchanged for decades during which time the energy codes were adopted and incorporated. No evidence exists that any actual field testing was performed which demonstrates that the ratings A or D have any actual effect on overall actual performance when installed on a structure. Similarly we find no evidence that any actual field testing on a structure which demonstrates that the principle defining parameter for "high vapor transmission" of 35 grams per square meter per hour was ever performed or that there is any basis to presume that this value has any real performance validity as relates to in service structures whatsoever. Finally, we note that these parametric values were adopted 50 years ago and well before writing of the energy codes. Structures at that period had relatively low or no insulation levels and thus high energy flux through the building envelope and were constructed generally in natural wood products such as real wood board sheathing.

Conditions at WRB Interface

Several barrier conditions exist at the interface between the sheathing and cladding which may be quite variable depending upon the type of cladding, sheathing, exposure, weather conditions and region. This is the location where the WRB exists.

A discontinuity of the vapor transmission rate exists due to building materials variations. The building codes and energy codes require vapor retarders generally on the interior surface of the building. In category 1 type construction this essentially requires complete sealing of the interior of the building envelope including electrical penetrations, ceiling penetrations, rim joists and the wall surfaces. Widespread use of synthetic sheathing materials which have extremely low vapor transmission rates and low water penetration rates some of which are labeled as "water repellant panel sheathing" by manufacturers results in an inadvertent vapor retarder located on the exterior of the wall cavity. This condition is located inboard of the WRB, thus, the vapor transmission rate of the WRB becomes immaterial.

A second condition exists at the interface between the cladding and the sheathing which results from essentially zero water penetration resistance at the wall cavity capped on the exterior with functionally water proof manufactured sheathing materials. Some commonly used sheathing materials such as OSB have been measured to have extremely low water penetration properties and are nearly waterproof. The addition of most approved WRB's over this type material in a vinyl or hard board siding application for example will only reduce drying rates of the sheathing and wall cavity.

At the interface between the sheathing and cladding, another condition exists which is in essence a cold plate effect or thermal barrier condition exists particularly with high density and high thermal conductivity cladding materials such as stucco and possibly other cementitious siding boards. This results from the sharp reduction in heat flux through the envelope mandated by the energy codes. The details of effects of the reduction in heat flux were shown in a preceding paper and will not be detailed here. An abrupt change between the temperature at the interface between the sheathing and the cladding exists with high mass cladding materials. This is the precise location at which the weather resistive barrier is located. Water or water vapor which enters the building envelope from either the exterior or interior condenses and accumulates at the surface between the sheathing and the cladding. This zone is occupied by WRB's of flat plastic sheet materials or paper pulp products as described above. The cladding and sheathing materials are held in close proximity by the construction with the WRB sandwiched tightly between. The commonly used sheet plastic and paper product WRB materials serve to hold water and increase the thermal conductivity between the cladding and the sheathing and serve to transport water into rather than remove water from sheathing materials.

Field Observations

Field observations have been taken at well over a thousand structures in which probe evaluations and/or invasive penetration inspections exposing framing, sheathing, WRB's and other elements of the structure were made. Probe testing is accomplished by drilling holes through the cladding into the surface of the sheathing. Two prong moisture probes are extended into the sheathing. The moisture content is measured and condition of sheathing typically judged as firm, soft or undetected providing some indication of condition of sheathing or of possible rot or softening in gypsum board sheathing. A second method of observation is by cutting holes through the cladding and sheathing or by removal of cladding or trim. A third method of observation is by monitoring of "tear off's" during restoration of a structure at which time the cladding and sometimes portions or all of the sheathing are removed during the repair and restoration process. A fourth method involves removal of or bore hole observations taken with optical probes through the interior surfaces usually gypsum board to observe wall cavities and sheathing/framing from the interior. In unfinished portions of homes (commonly the lower level), conditions are readily observable from the interior by removal of vapor retarder plastic sheeting and insulation. The combination of methods allows for a comprehensive evaluation of the conditions in the sheathing and building envelope.

Generally it has been found that moisture accumulation at the interface between the siding and the sheathing appears at several recurrent areas such as below penetrations in the envelope such as at doors, windows, pipe penetrations etc. Generally, water entry and accumulation conditions are found in locations at and below window and door penetration locations, below exterior deck/porch constructions, in wall cavities of lower level areas due to condensation and particularly condensation at the rim joist area. Other areas include wood frame chimney box out areas and locations below roof/wall intersections which are unvented and hence prone to effects of condensation. Certain other areas such as locations with heavy furniture, double walls or built in interior items such as cabinets and book cases on exterior walls causing localized hyper insulation effects and associated condensation conditions are also observed. It is common to observe water or ice and frost on the WRB, the sheathing and between layers of WRB. Moisture accumulation at in the WRB is very common. Liquid water is often observed on both the exterior surface of the WRB and between layers of the WRB. Moisture is commonly observed along with deteriorated sheathing and rot conditions in the framing depending upon the chronic nature and supply sources of the water or water vapor, exposure and other variables.

WRB's of the kraft type and paper type are often found to be melded together due to deterioration of the WRB's to the extent that care and close inspection may be required to ascertain whether more than one layer exists. Identifying the number of layers of WRB is important in litigation as some applications require multiple layers under the major codes and this issue is often a claimed item in construction defect litigation. Deterioration can occur quickly within several years depending upon multiple variables. The WRB's are often found to be wet while the cladding and sheathing are dry or dryer. Framing and sheathing surfaces on the interior of plastic sheet type WRB's have been measured to have higher moisture contents than those exterior to the WRB indicating that the WRB is causing moisture to be trapped interior to the WRB rather than keeping the moisture out or letting the moisture escape. Moisture content in sheathing and framing materials behind or interior to the plastic WRB's has commonly been measured to be higher than to the exterior of the WRB. This is in direct conflict with product claims made for such WRB materials and the theory advanced by the major building codes that the "high" vapor permeable WRB's improve drying of the sheathing and framing. In some instances dry exterior surface conditions on the synthetic WRB have been documented and saturated conditions to the immediate interior surface of the WRB at the same location. The wraps appear discolored from soluble materials exuding from the sheathing and siding. The soluble fractions are obviously filling and blocking the micro penetrations in the synthetic wraps and substantially altering the properties of the wrap materials with reductions in vapor transmission rate and water penetration resistance. The essential WRB properties are altered to a near water proof state which locks water behind the WRB.

In similar construction in the same time frame and same subdivisions, comparative observations were made of two adjacent residential wood frame structures with hard coat stucco siding over OSB sheathing. Both structures were approximately 7-8 years old at the time of the observations. Both structures had complete tear off of the stucco at the same time revealing the full extent of the sheathing. One structure was constructed with paper type WRB and the other with open weave type polypropylene WRB material. The OSB sheathing on the structure with the open weave type polypropylene material was observed to have no deterioration and sheathing appeared essentially in new condition. By comparison, at the structure in which paper base WRB was used, deterioration of the OSB sheathing was documented below the majority of window locations. The effect was determined to result from the unanticipated benefit of a thermal break between the cladding and the sheathing. This is provided by the space occupied by the open weave synthetic material and which is further protected by the low capillarity of the material. Both of these effects are advantageous with respect to reducing the accumulation of water at this interface and provision of a thermal break between the sheathing and cladding.

Effect of Cladding Materials

High mass cladding materials such as cementitious stucco have thermal conductivities which are an order of magnitude higher than sheathing materials and perhaps 1 – 2 orders of magnitude higher depending upon the sheathing material used. For example, the bulk density of fiberboard has been measured in the range of 18 pound per cubic foot and in fact is marketed as insulated panel sheathing as compared with other materials such as Oriented Strand Board (OSB) with bulk densities in the range of 40 – 50 pounds per cubic foot. The gypsum wall board sheathings have higher density and, thus, higher thermal conductivity than fiberboard or OSB type products. However, compared with cementitious products, the thermal conductivity is fractional. Thus, at the interface between the sheathing materials and the cementitious cladding material (stucco) a condition exists wherein the cladding material is relatively very cold compared with the sheathing materials and, thus, causes condensation. This condition was of less importance and did not result in chronic deterioration of sheathing or the building or framing prior to the Energy Code when insulation levels were low and heat flux was high. The higher heat flux in the pre-energy code construction caused sufficient drying of the materials to prevent problems of deterioration that are at this time widespread. Therefore, a thermal break in the area between the hard coat stucco cladding and sheathing should be considered. No such provision appears in the model codes. Rather, the codes provide for WRB's which actually have the adverse effect as described above.

Compared with high mass cementatious cladding materials, wood siding and vinyl siding have lower mass and low thermal capacities. The net effect is to reduce or eliminate the cold plate effect and resultant condensation at the WRB interface. Extent of deterioration of sheathing in wood siding and vinyl siding applications has been observed to be a very small fraction as compared with high density cladding applications.

Mathematical Modeling

Mathematical modeling using various computer programs has been performed by this writer and by others and reported in a prior paper. The computer based modelers, however, are elastic two dimensional modelers and do not account for dwell time with respect to the effect of mass in the cladding and do not account for the wetting of WRB and resultant increased thermal conductivity in that zone. Based upon extensive field observations, these conditions are believed to be significant. The high mass and high thermal conductance of stucco cladding and cement based wood fiber hard board siding result in a cold plate effect. The materials become relatively cold during the night time hours and resultant to the relatively higher mass are slower to warm than lower density siding materials such as vinyl and wood. This condition has been documented with infrared scanning in the field showing the differences in the surface temperatures. The two dimensional modelers, however, tend to show linear changes in the temperature gradients across the layers in the envelope. As a result, a temperature discontinuity occurs at the interface between the cladding and sheathing as described above which results in condensation and accumulation of water either from the exterior as so called "bulk water" or from vapor either from the exterior or interior of the building envelope. The effect is to accumulate liquid water in the area in which the WRB is located. Further modeling with more sophisticated techniques would better define the conditions and perhaps provide a rational basis for changes to the building codes in these areas.

Effect of Weather Resistive Barriers

An array of synthetic, paper and felt weather resistive barriers (house wraps) are in the marketplace in widespread and ever increasing use. Many are used for advertising and bear the logos of the builders. This has provided a commercial incentive for builders to use the wraps. As noted above, some states have mandated that weather resistive barrier is installed on the exterior of all sheathing regardless of building type or cladding type and the IRC now specifically requires WRB's on all structures for most types of cladding. No long term actual field testing was performed prior to making this universal requirement. Synthetic type weather resistive barrier materials, particularly kraft Grade D papers and plastic wraps, have claims made by manufacturers which are not supported by field observations. These materials have been observed to perform poorly in northern climates in construction conforming with energy code requirements.

Conclusion

Those practicing in the area of forensic engineering in the areas of building envelope conditions are advised to become knowledgeable in the areas of the applicable codes as well as published and unpublished industry standards of practice for the region, time frame and type of construction relevant to the litigation. Those practicing in these areas should become versed in the actual effects of the interaction of various elements of the building envelope and the conflicts in the building codes as relate to and cause adverse conditions and deterioration.