THE SHORTCOMINGS OF USING PRESCRIPTIVE SPECIFICATIONS WITH EMERGING ROOF TECHNOLOGIES

Rene M. Dupuis, Ph.D., PE
Structural Research, Inc.
Middleton, Wisconsin, U.S.A.

Mark S. Graham
National Roofing Contractors Association
Rosemont, Illinois, U.S.A.

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Abstract

Prescriptive specifications often are used by designers to define roof system designs. In many instances, these prescriptive specifications are out of date and inconsistent with current roofing technology. With the general public's sudden interest in using roof systems as reflective surfaces or platforms for vegetative roof systems or renewable-energy systems, designers' reliance on prescriptive roof specifications is of increasing concern because they usually do not properly address the specific performance attributes necessary for roof systems and changing materials and technology.

One already obvious example of the above-mentioned concern is a shift occurring within the concrete industry to using porous, lightweight aggregates in structural concrete instead of normal weight aggregates, such as those used in normal weight structural concrete. Although the benefit of using lightweight aggregates in structural concrete is obvious—lighter weight concrete structures—the unintended consequence

is the concrete's lightweight aggregate will store and release moisture to the detriment of the installed roof system.

This paper will review methods for determining the wetness (and dryness) of concrete substrates to ascertain the appropriateness for these substrates to receive roofing materials. Because the flooring industry has similar concerns, test methods used by the flooring industry also will be considered.

Authors

Rene M. Dupuis, PhD., P.E.

Mr.Dupuis has a Doctorate, Civil Engineering, University of Wisconsin, 1973; Master of Civil Engineering, University of Wisconsin, 1969; Bachelor of Civil Engineering, University of Wisconsin, 1968; Bachelor of Agriculture, University of Wisconsin, 1967. He is licensed to practice Professional Engineering in the States of Wisconsin Alabama.

Dr. Dupuis has conducted research on structures, roofing and waterproofing materials and systems for numerous industry groups including: American Society of Testing and Materials, United States Corp. of Engineering Research Laboratories, National Roofing Contractors Association and the Midwest Roofing Contractors Association. Dr. Dupuis has authored or co-authored over 80 publications regarding roofing and waterproofing materials and systems.

Dr. Dupuis is on the ASTM D-08 Roofing, Waterproofing and Bituminous Materials Committee and was the Task Group Chairman on Roof System Performance, Subcommittee D-08.20, and ASTM Committee D-08. He has served on a number of other committees including: the Roof Advisory Panel for the Department of Energy

(DOE), Oak Ridge National Laboratories (ORNL), Roofing Industry Educational Institute (RIEI) and International Committee on Single Layer Roofing.

Dr. Dupuis has presented Roof System Performance Seminars on a national basis for industry associations and universities. He maintains active participation in American Society of Civil Engineers (ASCE), National Society of Professional Engineers (NSPE), Construction Specification Institute (CSI), Single Ply Roofing Institute (SPRI) and American Society of Testing and Materials (ASTM). He has provided numerous investigations and evaluations on all types of roof systems and has provided complete design services for a wide variety of public and private clients. Dr. Dupuis is highly regarded in the industry as an authority on roofing and waterproofing materials and systems.

Mark S. Graham

Mark S. Graham holds a Bachelor of Science degree in Architectural Engineering from the Milwaukee School of Engineering. In 1984, he began his career in the roofing industry when he joined F.J.A. Christiansen Roofing Co., Inc., in Milwaukee, Wisconsin, as an estimator and project manager. In 1986, he joined Wiss, Janney, Elstner Associates, Inc., in Northbrook, Illinois, as a project engineer specializing in the investigation, design, and repair of roofing and waterproofing systems.

Mr. Graham joined NRCA in 1993 and is responsible for the association's technical services section. Responsibilities of this section include response to inquiries for technical information and assistance, serving as the association's technical liaison with outside organizations, and developing and maintaining the association's technical documents, including *The NRCA Roofing and Waterproofing Manual.* Mr. Graham is the staff liaison to NRCA's Technical Operations Committee and Manual Update Committee. He is also a contributing editor for *Professional Roofing* magazine.

Mr. Graham is a member of the American Society for Testing and Materials (ASTM) and is active in ASTM Committees D-8 -- Roofing and Waterproofing, C-16 -- Thermal Insulation, E-5-- Fire Standards, and E-6 -- Performance of Buildings. He is also a member the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), International Code Council (ICC) and National Fire Protection Association (NFPA).

He and his wife, Ann, have two children, Nicholas and Lindsey, and they reside in Naperville, Illinois.

The Shortcomings of Using Prescriptive Specifications With Emerging Roof Technologies

Prescriptive roof specifications are in wide use and many times misapplied, out of date or otherwise almost tangential to the true scope of work needed for a successful roofing project. It is possible that the majority of prescriptive specifications that currently exist on computer hard drives are outdated and riddled with antiquated citations of ASTM International standard references and codification errors.

Two factors typically come forward in roofing projects to diminish or supplant the effects of the faulty prescriptive specification preparation. The first is awarding the roofing work to a qualified, experienced roofing contractor. The second is using a widely recognized roof specification from a well-established roofing manufacturer. A good contractor or experienced technical representative from the roofing manufacturer often simply will proceed to install a generic roof system, sidestepping a faulty and out-of-date design specification.

This procedure has worked well as a checks and balances; millions of squares of roofing materials have been installed successfully using this checks and balances process.

Historically, roof construction generally has drawn little or no interest from the general public; only building owners have an appreciation of the checks and balances system because the owner sponsored the work and received the hallowed roofing warranty.

Now, the general public—society in general—is beginning to become more interested in all roofs, low-slope and steep-slope. Roofs now are regarded as usable sites for hosting:

- Vegetative roof systems, ranging from tray systems to highly engineered bulk soil placements on top of a roof or waterproofing system
- Renewable-energy collectors such as photovoltaic systems or other solar heat collection devices
- Highly reflective or cool roof membranes for any roof surface not covered with the systems outlined in the two previously mentioned systems

As a result, the use of canned, outdated prescriptive specifications becomes even more problematic as the operational demands and realities of the previously described roof system configurations manifest themselves, overwhelming and exposing fatal flaws in the prescriptive specifications used.

A number of technical issues have become apparent through roof systems' failed performances and shortened service lives. These include:

- Moisture migration from the building's interior inexplicably wetting or saturating roof system components
- Condensation dripping into the building's interior
- Loss of adhesion within fully adhered roof systems
- Unexplained formation of ice on the bottom side (underneath) mechanically fastened single-ply membranes, especially in roof system configurations with only a single layer of rigid board insulation

Recent Research

Several pieces of recent research are relevant to these topics:

- The formation of heavy condensation layers below cool membranes has been studied and reported on by Rose[1] in 2007. This research effort identified key parameters of energy exchange from a roof surface at night into deep space; the super cooled membrane caused entrapped interior air to reach its dew point, depositing free water. A cool roof membrane cannot generate enough heat to accomplish dry down, something the conventional dark-colored membranes quietly have accomplished without scientific oversight or appreciation.

  Rose's work presented the theory of steady state heat balance a roof would see, including solar absorptance, solar insolation, thermal conductance of the insulated roof assembly and surface emissivity. Basically, highly emissive roofs emit energy under clear skies. Highly reflective roofs cannot compensate for the energy lost to the sky because of their limited solar gain. Therefore, a moisture gain under the membrane may occur, driving up from the building interior or materials of construction.

- Nicastro and Klein[2] have summarized the detrimental effects of moisture laden to fluid-applied roof or waterproofing systems installed over lightweight (lightweight aggregate) structural roof decks, including biological growth on organic materials in the roof/waterproofing system.

  Their work concluded that lightweight structural concrete releases moisture for a much longer period, negatively affecting the roof/waterproofing system because of the

[1] Bill Rose, "The White Roof Problem in the U.S. Desert Southwest, " Thermal Performance of Exterior Envelopes of Whole Buildings X, December 2007, Clearwater Beach, Florida

[2] Anthony Nicastro, PE, and Kenneth A. Klein, PE, "Moisture Problems Overhead: Lightweight concrete in roofing and waterproofing applications," The Construction Specifier , September 2009, pages 34 – 41.

membrane's inherent low permeability. Lightweight structural concrete used over metal decks also is problematic as metal decks significantly restrict moisture vapor transfer downward to a building's interior. Also, a low-perm membrane on top of the lightweight structural concrete in the form of a roof system or directly applied waterproofing membrane restricts upward flow of water vapor, preventing upward moisture vapor transfer and venting.

The use of "vented" metal form decks is no panacea. There is a dearth of scientific data regarding vented metal form decks. No standards exist, there is not even scant empirical data to rely on; it is a case of designer, beware.

- For various reasons, newly poured cast-in-place concrete roof decks are being changed to using lightweight structural aggregates instead of normal weight aggregates. This change yields in place concrete weights of 90 to 120 pounds per cubic foot, a weight savings of 30-50 pounds per cubic foot over normal weight structural concrete. The resulting lightweight structural concrete offers similar strength and longevity of normal (heavier) weight structural concrete.

  The weight savings leads to lighter structures and contributes to sustainable development by lowering transport costs and maximizing design, which lead to construction efficiency. Although lightweight aggregate had been used for structural concrete sparingly in the past, the current push on sustainability and conserving energy and materials has brought more attention to lightweight structural aggregate. Another benefit is in seismic design because it lessens the floor and roof deck mass response to ground motion. In addition, lightweight structural concrete reportedly has better fire resistance per ACI 213R-03[3].

- One single-ply manufacturer issued a design bulletin in 2006 warning of construction generated moisture. SPRI issued a bulletin[4] in August 2008 outlining the effects of construction-generated moisture on roof systems. Others have reported anecdotal evidence of condensation issues with highly reflective roof systems.

Moisture Retention Behavior of Lightweight Aggregate

Lightweight aggregate is porous. As a result, it must be pre-wetted—or presoaked—before batching the concrete mix. Because of lightweight aggregate's void structure, water critical to cement hydration may be taken from the mix by the lightweight aggregate. As a result, this type of aggregate needs special attention before batching. Pre-wetting aggregate with sprinkler hoses may take days or weeks in a bulk pile; the more precise method is to pond and water soak lightweight aggregate.

If pre-wetted properly, the lightweight aggregate material will not weaken the mix.

ACI 213R-03 cites a number of moisture issues relative to normal weight concrete. Section 2.3.7 on moisture content and absorption describes how in 24 hours, lightweight aggregates can absorb anywhere from 5 to 25 percent of their mass dry weight in water. By contrast, normal weight aggregate concrete will absorb less than 2 percent of moisture. This water is taken into the pore system; with normal aggregate, the water mostly would reside on the surface.

[3] ACI 213R-03, "Guide For Structural Lightweight-Aggregate Concrete," American Concrete Institute (ACI).

[4] SPRI Advisory Bulletin, "Construction-generated Moisture and Its Effect on Roofing Systems," SPRI, August 2008.

Lightweight aggregate therefore must be pre-wetted; this increases the density of the fresh concrete. Because the increased pore density is increased by free water, that higher density eventually will be lost to dry down, which causes extended internal curing (dry down) to occur over time.

Of interest is what happens to the free moisture once the concrete slab is poured. Low-perm coatings or roof coverings run the risk of delaminating or, in the case of an insulated roof assembly, the unintended consequence of uncontrolled moisture gain occurs.

Moisture Gain

When considering moisture content, roof assemblies are not static. Many construction materials (wood, concrete, paper, gypsum and masonry units) have equilibrium moisture content. For instance, wood will change dimension with moisture loss or gain while other materials may not demand a notable dimensional change. But all these materials will change moisture content depending on temperature. What these materials cannot control is moisture gain because of building operation, concrete materials drying down or the cumulative moisture newly constructed buildings are known to have.

Roof systems on our school buildings have performed successfully for decades, many times with no vapor retarder on the deck. Dark-colored roof systems run at higher temperatures and cause down venting to slowly occur in the summer months where steel or wood decks are used. Concrete decks, especially lightweight structural concrete, are known to contain moisture because they are cast in a wet state using aggregate with voids. Not all mix water is taken up in hydration. Additional moisture from high building humidity may be taken up into the void structure of lightweight structural concrete.

What we are beginning to see is one-way moisture gain under highly reflective roof membranes that cannot reverse themselves because of the cool roof environment. If the roof system runs at a cool temperature during the day and cold at night, no meaningful dry down can occur.

There are millions of square feet of light-colored roof membrane installed in the continental U.S. that have been operating satisfactorily for years. Many of the earlier light-colored single- ply membranes were mechanically fastened. We now have new adhesives and cover boards that are easy to design and install with fully adhered membranes. It is the mechanically fastened, light-colored systems that need more design scrutiny, especially if a single layer of insulation is used over a steel deck. Fresh cast-in-place lightweight structural concrete can impose a moisture load on a new roof system, even with multilayered insulation boards and a dark fully adhered membrane.

There is ample evidence from past studies that roofs do dry down. If one carefully designs a reroofing system to install over lightweight insulating concrete (LWIC), it is possible to dry down wet LWIC deck that has been problematic. Sloped metal roof systems installed over wet, low-slope built-up roof (BUR) systems have been known to dry the BUR when properly designed and constructed.

If you closely examine what happens, you quickly will realize that heat, moisture, thermal mass and the ability to absorb moisture are interrelated for roof systems. Steel as a material will not absorb moisture; use it in thin sheets and it eventually will corrode in a high-moisture environment. Wood products, thick or thin, will take up moisture.

Materials with little mass (recycled paper facer on insulation) only can hold a limited amount of moisture. This is true for moisture driven into the roof system by condensation or moisture from a roof leak. Cover board products typically have more mass and a greater ability to absorb excess moisture and let it go upon heating. For decades we have used wood fiber board under BUR as a cover board. What few designers understand is that wood fiber board easily would expand and contract with that needed by the BUR while being in a state of elevated moisture content. Many buildings with this particular roof system did not use vapor retarders; therefore, we came to understand how these roof systems took up excess moisture vapor (condensation in small amounts) and gave it up the following summer when the dark-colored membrane became hot. By the time cold temperatures returned, the system had dried down and was ready to go again. Coal tar roof systems with organic felts worked that way for many decades.

Methods of Detecting Moisture—Concrete Roof Decks

The roofing industry historically used a hot mopping of bitumen applied to a concrete deck as a recognized field test procedure for detecting surface moisture. If the hot bitumen (400 F) bubbled and popped, it was understood that moisture was in the surface region of the concrete deck, turning to steam and venting out of the hot viscous bitumen by first bubbling and then forming pin holes in the cool bitumen. Although not scientific, it told a contractor whether the concrete deck surface was dry enough to prime and mop. The mopping of bitumen would serve as a vapor retarder (with 100 percent unbroken coverage) and act as an adhesive for the felt or insulation board laid into it. The hot bitumen field test procedure rarely is used today because the use of mechanical fasteners, low-rise foam adhesives and cold-process adhesives greatly have diminished the use of hot bitumen for many roof systems.

A second method is to tape a clean sheet of polyethylene film to the deck and leave it for at least 24 hours. This film test also is known as ASTM D4263, “Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method.” Checking the film for fogging or condensation on the underside after being in place overnight would indicate moisture in the concrete slab’s upper regions. Although it is a more definitive qualitative test than applying hot bitumen to a deck, the poly film test can be misleading because false positives can occur. A dry film after 24 hours revealed nothing about the moisture condition of the concrete deck material below the immediate surface. This is partly because of the various concrete finishing techniques that can be employed during concrete placement. Heavy steel traveling could bring “fines” to the surface, enriching it and acting as a retarder to water vapor flow. Application of a temporary liquid sealer or curing compound to the concrete to prevent rapid drying also would give misleading results when using the plastic film test.

Methods of Detecting Moisture—NRCA’s Guidelines

NRCA, in *The NRCA Roofing Manual: Membrane Roof Systems-2011,* provides the following discussion regarding moisture in structural concrete roof decks:

“Curing and Drying: Normal-weight and lightweight structural concrete contain significant amounts of water when mixed, formed and poured, and finished. As concrete cures and hardens, it consumes large amounts of this water through hydration and evaporation. For example, a 4-inch-thick concrete slab will release about 1 quart of water for each square foot of surface area.

Historically, the roofing industry has used a minimum 28-day period as a guideline for applying roofing materials over newly poured concrete roof decks. This 28-day period coincides with the curing time for concrete before it is tested for design compressive strength. There is little technically justifiable correlation between this 28-day period and concrete's actual dryness and appropriateness to be covered with a membrane roof system.

In some instances, a plastic sheet has been used to determine concrete's dryness. With this test, a plastic sheet (4-mil-thick polyethylene) is taped to the concrete surface and the plastic sheet's underside is monitored for the presence of condensation. ASTM D4263, 'Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method,' defines this test method.

NRCA is of the opinion that the plastic sheet method is not a reliable means for assessing newly poured concrete's dryness.

The concrete industry has seen significant advances in technology in concrete mix design, placement and technology that can affect concrete's curing and drying times.

For example, the use of concrete additives in concrete mix designs and concrete curing can greatly accelerate or retard concrete's curing and release of free moisture. Similarly, weather conditions, covering newly placed concrete, and temporary heating or ventilating a building's interior can affect the rate of concrete's upward or downward release of free moisture.

For these reasons, NRCA does not support the 28-day drying period or the plastic sheet test.

NRCA considers the decision of when it is appropriate to cover a newly placed concrete substrate to be beyond roofing contractors' control. Because of the numerous variables associated with concrete mix design, placement, curing and drying, roofing contractors are not privy to and may not be knowledgeable about the information necessary to make such a decision.

Also, though a roofing contractor can visually assess the dryness of concrete's topmost surface, he or she cannot readily assess any remaining free moisture within the concrete and its likely release.

NRCA recommends the decision of when a newly poured concrete substrate is ready to be covered with a new roof system be made by the building's structural engineer, general contractor, concrete supplier and concrete placement contractor each of whom will likely have more knowledge of the particular concrete's curing and moisture release rates than the roofing contractor. It also may be useful to consult the building's project or roof system designer and roof system manufacturer."

Methods of Detecting Moisture—Concrete Floor Slabs

Similar to roof assemblies, the performance of resilient floor coverings, coatings and adhesives can be adversely affected by excess moisture in concrete floor decks, especially slab–on-grade construction. However, unlike the roofing industry, a large amount of research was done by concrete and flooring specialists to better understand the moisture vapor emission rate of new concrete floor slabs.

A test using calcium chloride allowed for quantifiably measuring the amount of moisture coming out of the surface of a slab before installing flooring, coatings or adhesives. Curves have been established that relate the weight of water vaporizing out of a concrete slab per 1,000 square feet in a 24-hour period versus the time to dry down to a 3-pound level based on various water to cement ratios used in the concrete mix. This work was undertaken by the Portland Cement Association in 1965 by Harold Brewer[5].

As reported by H. Kanare[6] and P. Craig[7], the calcium chloride test now is known to have limitations. Field variables such as ambient conditions present during the test now are recognized as limitations to the ASTM F1869, "Standard Test Method for Measuring Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride." The physical set-up of this test is similar to the plastic film test. Instead of looking for condensation on the back side of the film, a quantity of anhydrous calcium chloride is weighed precisely before and after to determine the moisture it absorbed coming out of the concrete surface while covered with the film.

A number of countries outside the U.S. began measuring the in-situ relative humidity of concrete slabs in the 1980s. A good history of the relative humidity probe test, as well as all other known methods of measuring moisture in concrete, can be found in "Concrete Floors and Moisture" by H. Kanare[8], published in 2008.

In 2002, ASTM International approved ASTM F2170, "Standard Test Method for Determining Humidity in Concrete Floor Slabs Using In-Situ Probes." Acceptable levels

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[5] Brewer, H. W., *Moisture Migration—Concrete Slab-on-ground Construction,* Research Department Bulletin DX089, Portland Cement Association, Skokie, Illinois, May 1965

[6] Howard Kanare, "Why are we still having problems with moisture in concrete floor slabs?" Concrete Construction, November 15, 2007.

[7] Peter Craig, "Problem Clinic: Moisture Problems with Concrete Slabs," Concrete Surfaces, March 2007

[8] Howard M Kanare, "Concrete Floors and Moisture," Portland Cement Association and National Ready Mixed Concrete Association, 2008.

of relative humidity within the body of the concrete slab range from 75 to 90 percent for flooring products. Individual materials are being evaluated by different flooring manufacturers to more readily predict performance of their products based on relative humidity within the slab.

Examples of Unintended Moisture Gain

The authors have reviewed, studied or inspected a number of new and reroofing projects that suffered unintended moisture gain within two years of installation. One common thread is the use of layered or tapered polyisocyanurate insulation boards adhered to a lightweight structural concrete deck with beads of low-rise foam adhesive. These roof systems range from the northeast, southeast and southwestern parts of the U.S. Some of these roof assemblies had cover boards—most did not. They all had fully adhered single-ply membranes either white or black in color. All roofs had parapet walls ranging from 24 inches to 8 feet.

The common mode of failure was loss of attachment as the fiber reinforced paper facer became wet, allowing a portion of the facer to stay with the bead of adhesive on the concrete deck. The remaining layered insulation system either moved dimensionally from moisture gain or was uplifted by wind. Figures 1-6 illustrate the field conditions encountered when examining these systemic failures.

The insulation facers generally had encountered enough moisture to support mold growth of varying strains. The insulation board's moisture content shown in Figure 3 (Test Cut #2) on one of the roofs observed was at 16 percent by weight. It is not known what level of moisture take up ultimately was reached by the insulation and facers before the dimensional change occurred.

In-Situ Relative Humidity Measurements

Several of the roof system installations that experienced loss of attachment and systemic moisture gain were made available for instrumentation. It was decided to use the plastic sheet test ASTM D4263 along with the latest technology of drilled probe holes using current technology specified in ASTM F2170.

The authors are not aware of any work of this type performed on existing lightweight structural concrete (LSC) roof decks covered with fully adhered single-ply using adhesives. The roof systems were located in the northeast, using LSC over metal form deck with near identical roofing specifications (different manufacturers, installers and owners).

An independent construction engineering firm with extensive experience with concrete testing and ASTM F2170 probe analysis was contracted to install plastic sheet and moisture probes on three roof decks on facilities in two adjoining states. The results are shown in Table 1.

The plastic sheet test had positive (light to heavy condensation) and negative results (no condensation) yet the probe data show no such variation of wet and dry. These findings support our position that using the plastic sheet test can be misleading.

The high probe readings indicated that a moisture condition still exists in the LSC roof decks. This is not surprising because of the low-perm ratings of the roof membrane on top and metal form deck below. The only absorbic materials present are unfortunately in the compact roof cavity between the deck surface and roof membrane. Free but hindered air flow can occur within the insulation assemblage because of the mechanical nature of bead adhesive construction. Mold was observed **in** various layers of the polyisocyanurate fiber reinforced paper facers.

Roofing Industry Needs

With designers' heavy reliance on prescriptive roof specifications and the general public's newfound interest in roofs (reflective roof surfaces, vegetative roof systems, renewable energy platforms), the roofing industry must prepare itself for new technical challenges.

One such area of new technical challenge is the concrete industry's change to using lightweight aggregates in concrete mix designs, such as those used for lightweight structural concrete roof decks. It is clear the roofing industry has done little to stay abreast of the change in concrete technology, increasing use of lightweight aggregates and, more important, how to properly assess a concrete roof deck's acceptability with regard to moisture emission up into a roof system. The U.S. flooring industry has followed other countries' lead into the use of in-situ probes. Some technologists argue that the in-situ probes (ASTM F2170) and calcium chloride test (ASTM F1869) need to be run.

Because concrete roof decks are exposed to the weather and temperature change, the calcium chloride test is severely limited. The use of hot asphalt, poly film or electronic handheld instruments is limiting and not of quantitative character.

The authors propose the roofing industry move to evaluate the use of in-situ moisture probes for roof decks following or modifying the procedures in ASTM F2170. Exploratory work will be needed to determine what existing systems recently installed over concrete decks are yielding in terms of in-situ relative humidity. We could use the guidelines of the flooring industry as a starting point.

This issue also is relevant to the use of low-rise foam adhesives to adhere roof system components to concrete roof decks. The use of low-rise bead foam adhesives by definition leaves large surface areas of concrete deck in direct contact with the insulation board. The moisture vapor emission rate will increase once the roof system is installed and the deck warms to near interior ambient conditions. Shallow passageways for horizontal air movement abound in this type of construction versus solid moppings of hot asphalt.

Little appreciation of solidly mopped construction was noted in the past. It now is apparent that all the changes made to improve a roof system's performance come at a price for not fully understanding the technology left behind.

TABLE 1: ASTM International F2170 Standard Test Method for Determining Humidity in Concrete Floor Slabs Using In-Situ Probes

	Deck 1	Deck 2	Deck 3
Roof age (years)	4	7	7
Roof area	13,200 square feet	23,840 square feet	14,760 square feet
Deck thickness	6.5 inches	7.5 inches	7.3 inches
Number of probes used	13	10	8
Highest probe reading	99 percent relative humidity (RH)	99 percent RH	99 percent RH
Lowest probe reading	63 percent RH	96 percent RH	84 percent RH
Median probe reading	97 percent RH	99 percent RH	99 percent RH
Mean probe reading	88.5 percent RH	98.7% percent RH	94.8 percent RH
Average deck temperature	70.3 F	74.7 F	72 F
Standard deviation	13.1 percent	1.9 F	3.9 F

Photo 1 The photo demonstrates the typical condition of a recently installed fully adhered roof system over lightweight structural concrete. Bead adhesives were used to install insulation boards directly to the deck; no cover board was used.

Photo 2 Bead adhesives on lightweight concrete deck show portions of insulation facer attached to adhesive; insulation boards had lifted.

Photo 3 This is another area of the roof described in Photo 1 showing pronounced dimensional stability issues with polyisocyanurate insulation board because of high moisture in new lightweight structural concrete deck.

Photo 4 The roof system identical in specifications to that described in Photo 3 and is constructed over newly poured lightweight structural concrete. The building is located in adjoining state.

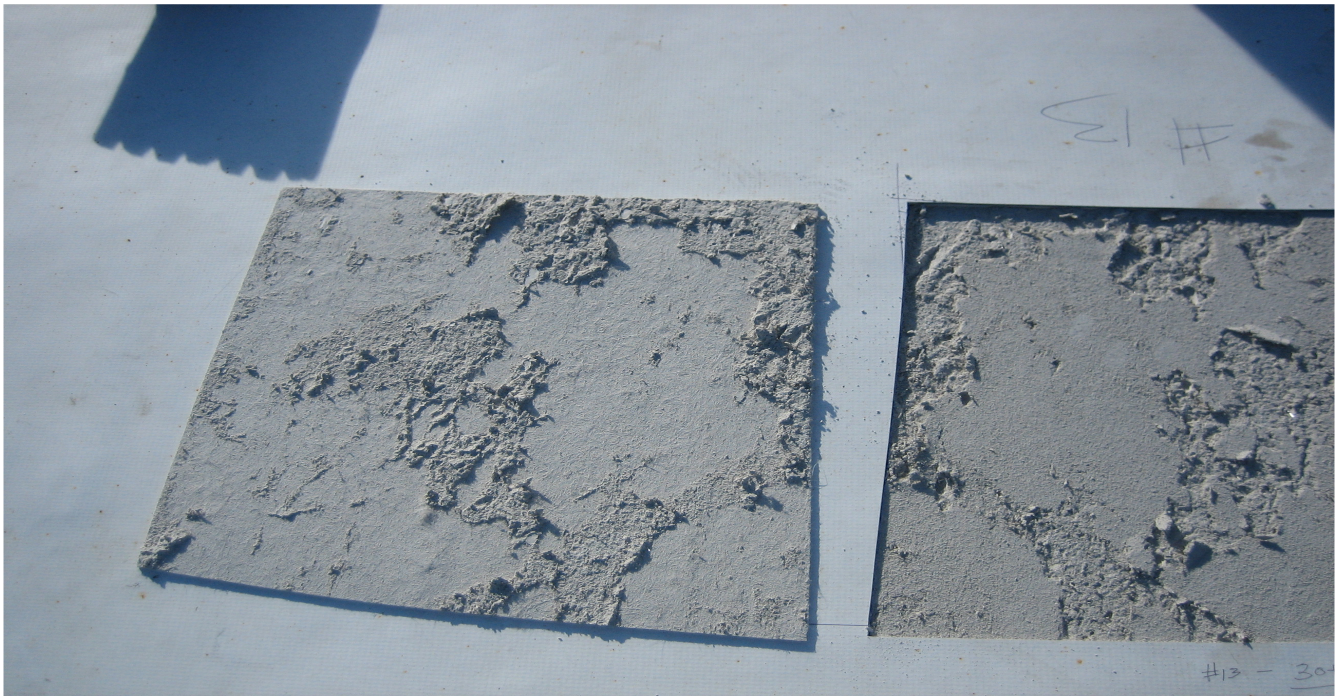

Photo 5 The new construction in a western state had a fully adhered roof system, white membrane and gypsum cover board. Moisture from the lightweight structural concrete deck drove up into roof system, wetting the cover board.

Photo 6 The photo demonstrates 3-inch single-layer insulation below the cover board in Photo 5. The moist insulation facer parted from bottom insulation facer is a typical consequences of moisture gain from new lightweight structural concrete observed in studying this type of deck construction. Wind uplift initiated discovery of problem.