REROOFING OVER FAILED ROOFS CONTAINING MOISTURE

An ORNL/RCI/SPRI Collaborative Demonstration Project

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Abstract

Although widely practiced within the roofing industry, roof re-cover, particularly over failed roofs that contain significant amounts of moisture, remains a controversial issue. The key issues surrounding this debate are the drying of wetted insulation, deck deterioration (dry rot of wood, disintegration of concrete, corrosion of metal), and fastener failures. To address these issues, a consortium made up of SPRI and its member companies—the Roof Consultants Institute (RCI) and the Oak Ridge National Laboratory (ORNL)—have initiated two demonstration projects to re-cover failed roofing systems containing moisture and to monitor the performance of those roofing systems after the reroofing.

In 1997, SPRI identified a building, the New Bethel Fellowship Church in Rossville, IL (approximately 100 miles south of Chicago) that satisfied criteria developed by SPRI for a satisfactory demonstration site. Representatives of SPRI, RCI, and Oak Ridge National Laboratory visited the building and, with the permission of the church, used this building for a demonstration project. The reroofing was performed in June 1998.

The roof has been continuously monitored, and yearly visits to the building for inspection and sampling purposes have been undertaken. Evaluating the compressive properties of the original insulation has been used to monitor the adequacy of the existing roof as a substrate for the re-cover roof. Fastener pullout testing has been employed to monitor the structural integrity of the deck and the corrosion protection of the fasteners. Measuring the moisture content of the existing and re-cover insulation examined whether the original roof is drying and whether the re-cover roof was being compromised by water from the original roofing system. Moisture content data were also used to assess a computer model that has been developed to predict the drying rates of roofing systems containing wet insulation. Finally, the reflectance of the membranes was catalogued to determine how rapidly white membranes foul due to dirt accumulation and degradation and their impact on the drying process.

This paper describes the building selection, reroofing process, data collection, and nondestructive analysis that have been performed to determine if the old roofing system is drying and to assess whether the fasteners have been adversely affected by the wet insulation material. Computer simulations of the roof system have been performed to predict drying; these data are compared to actual core measurements and nondestructive test results to determine the drying rate of the re-covered roof systems.

Introduction

Re-covering roofs continues to be a popular method of reroofing. The NRCA Annual Survey for 1998 indicates that re-cover now represents approximately 1/3 of all roofing activity [1].

The same source reports that reroofing now represents over 3/4 of all U.S. low-slope roof construction. The decision of whether to replace or re-cover a roof occurs 75% of the time that the roofing industry is called upon to perform its job. Even with this renewed interest in reroofing, only conservative, unsubstantiated guidelines have been brought forward to aid the roofing professional to make this everyday decision.

Market forces and environmental issues have clearly led to the increased use of re-cover. With increased emphasis on producing sustainable building systems, re-cover offers the building owner the opportunity to reuse portions of the existing roof system, reducing the amount of construction and demolition waste generated by the roofing industry.

Water is the universal concern in reroofing; a roof leak typically initiates the process of determining whether an existing roof system can be repaired or requires reroofing. Clearly, every roof should not be re-covered. To successfully re-cover an existing roof system that has failed and has water trapped within its cross section, the only means of removing that water in a timely fashion is to have it diffuse downward into the building interior. An estimate of the drying rate must be known to determine whether the components of the new and existing roofing systems can regain and maintain adequate physical properties to perform properly once the drying has been completed.

Without this information, the roofing professional is simply guessing the best course of action. Experience in reroofing is helpful but limited because of the number of variables that impact the decision to reroof over wet insulation. He or she may choose the conservative route and require that every wetted portion of a roof be replaced. Given the business climate, he or she may gamble on winning an award by proposing to re-cover that roof without sufficient information on the long-term effects of that proposal.

A means of determining the correct course of action is computer simulation. Knowing the amount of moisture contamination, roofing system construction, location of the building, and the interior conditions, roofing systems can be modeled to quickly determine if they will dry within a reasonable period of time. However, most computer simulations require that simplifying assumptions be made and the roofing industry has traditionally resisted these techniques as decision-making tools until they were validated with field experiments.

Figure 1. The New Bethel Fellowship Church in Rossville, IL

Recognizing this need, a consortium made up of SPRI and its members, the Roof Consultants Institute (RCI), and Oak Ridge National Laboratory, planned, organized, and performed a whole roof re-cover on the church building in Rossville IL. This paper summarizes that joint project.

The Building Selection

In 1992, the SPRI Re-cover Subcommittee proposed that a whole building demonstration experiment be performed that would generate the necessary data to address concerns about roof re-cover and developed specifications that the ideal test building should possess. The subcommittee was searching for a building that met the following criteria:

- The size of the building should be large enough to be considered representative of a typical building but small enough to control the cost. Ideally, the building should be between (3,000 and 10,000 ft^2 (280 and 930 m^2);
- The building should ideally be located in a northern climate and have a conditioned interior;
- The roof system must be contaminated with an appreciable amount of water;
- The roof system must have the potential to dry downwardly (no vapor retarder);
- The roof system should be as "typical" as possible, i.e., have a metal deck, some insulation, and a traditional membrane;
- The deck must be structurally sound;
- Access to the roof, edge detailing, and all other aspects of the reroofing should be considered to minimize the overall project cost;
- The building owner must be willing to allow performance of an experiment on his building; and
- Ideally, the building should be owned by a nonprofit organization that would benefit from the reroofing project.

The New Bethel Fellowship Church

In 1997, SPRI identified a building, the New Bethel Fellowship Church in Rossville, IL (approximately 100 miles or 160 km south of Chicago), that satisfied most of the criteria developed by SPRI for a satisfactory demonstration site. The building is pictured in *Figure 1*. It was a one-story structure that originally served as the town's market. The building had two roof planes and a total roof area of 11,000 ft^2 (1020 m^2). The main roof plane made up 95% of the entire roof area. The second roof plane covered a small service elevator at the rear of the building.

The existing roof was comprised of an 18 gauge metal deck with 18 gauge metal panels welded to the underside, 39 mm or 1.5 inches of perlite insulation spot-mopped with asphalt to the deck, and an aggregate-surfaced, four-ply organic felt and asphalt BUR. In addition, an asphalt base sheet with a liquid-applied aluminum coating had been applied over the BUR in what appears to be a reroofing attempt. The roof had a 1:12 slope that peaked in the middle, equally dividing north and south on each side. The building owner informed us that the original roof was approximately 25 years old. The current owner had acquired the building in 1994, and it had been leaking since that time. The age of the attempted reroofing is unknown. Numerous ineffective temporary repairs were apparent, and the church was financially incapable of replacing the roof.

Representatives of SPRI, RCI, and Oak Ridge National Laboratory visited the building in September 1997. During that visit, they met with church officials to discuss interest in their building, to assess their willingness in participating in the project, and to examine the roofing system. A visual inspection of the roof was performed and several core samples taken to verify the roof components and the absence of a vapor retarder. The core samples were also used to determine the amount of moisture in the roofing system. Fastener pullout tests were made to use as an indicator of the structural condition of the metal deck. Shortly after the visit, a nuclear densometer moisture survey was performed on the roof to determine the extent and location of moisture contamination.

In summary, the roof system satisfied most of the developed criteria. Permission was obtained from the owner to use the building as a test site and to proceed with the project.

The Reroofing

The reroofing was performed during the fourth week of June 1998. After removing any loose coated felt and brooming off any loose aggregate, 1/2-inch (13mm) wood fiberboard (WFB) in 4 by 8 ft. (1.2 by 2.4 m) sheets was mechanically attached from the eaves and the north and south sides approximately half way up to the peak, using fasteners with a compliance-grade base coating that meets the minimum requirements of FM 4470. The remaining roof surface was insulated with 2-inch (51mm) polyisocyanurate foam (PIR) in 4 by 8 ft. (1.2 by 2.4 m) sheets attached in a similar manner as the wood fiberboard.

Approximately half of the roof area was covered with a black or white thermoplastic olefin (TPO) single-ply membrane. The membranes were mechanically attached. White membrane was used on the western half of the roof while black membrane was used on the eastern half. Since two manufacturers donated membrane, the roof was further split to accommodate the inclusion of their membranes. *Figure* 2 depicts the layout of the insulation and membranes. The flashings were redone, and new edge metal was applied around the roof perimeter.

The building was reroofed in this manner because of the interest in examining the effects of roof color and re-cover insulation R-value on the drying rate of the roof system. The black and white ethylene/propylene membrane had as-installed solar reflectances of approximately 0.05 and 0.8, respectively. These values of solar reflectance approximate the limits of membrane color used in roofing applications. When re-covering a roofing system, a small quantity of insulation is typically used to separate the new membrane from the existing roof system. If the existing roof system has little or no insulation, the reroofing may include an appreciable amount of insulation. These two extremes were captured with the two types and thicknesses of insulation installed.

Because of the interest in modeling the roof system, instrumentation was installed in the roof system during the reroofing.

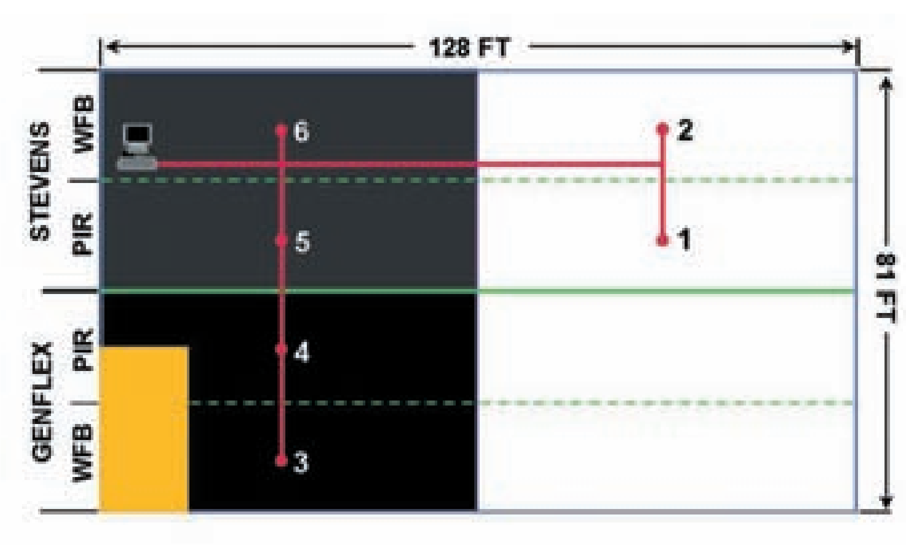

Figure 2.Schematic of re-cover insulation, membrane, and instrumentation layout.

Six temperature sensors were installed directly under the membrane while two sets of temperature and relative humidity sensors were installed inside the building. These sensors would be used as the boundary conditions of the modeling efforts; the sensors below the membrane would effectively define the climate side of the roofing system while the sensors below the deck would monitor the indoor conditions. All of the instrumentation was connected to a data acquisition system (DAS) installed in the building. The DAS sampled the output of each sensor every minute and computed 15-minute averages that were stored in memory for subsequent analysis.

When the re-cover was completed, the roof was marked off in a grid pattern on 5-ft. (1.5m) centers. Each intersection of the gridlines was given a two-number ID; the two numbers identified the location of all the intersections from the southwest corner of the roof. The first digit identified the intersection's distance (in feet) from the southwest corner in the north-south direction while the second digit identified the same parameter in the east-west direction. A nuclear densometer moisture survey was then performed on the roof. This survey would be used as the baseline to determine the drying rate of the roof.

Based on this survey, seven locations were identified on the roof that covered the range of outputs measured by the nuclear densometer. 2-inch or 51mm diameter core cuts were taken at these locations and the moisture content of the existing perlite and re-cover insulations from the core cuts were determined gravimetrically. These data were used to calibrate the nuclear densometer and the moisture reading at each intersection of the roof grid was converted to moisture content.

Field Sampling After the Reroofing

In October 1998, four months after reroofing, the research team returned to perform another nuclear densometer moisture survey. The roof was revisited in June 1999 for more extensive sampling. During this second visit, 450mm or 18-inch square sections of the roof were removed at each of the seven locations sampled in 1998. At each location, the membrane was cut to expose an insulation fastener. After verifying that the fastener was tight, the fastener plate was cut off, and foam around the fastener was cut away so a fastener withdrawal test could be performed. After testing the existing fasteners, a 12-in. (300 mm) square section was cut out of the BUR and existing perlite insulation. Specimens of the re-cover insulation, perlite, and membrane were coded, placed into plastic bags, and shipped to laboratories for subsequent testing. New fasteners were installed into the deck and pullout tests performed as an indicator of the deck's integrity. All of the pullout tests yielded results in excess of 3100 N (700 lbs.); this pullout force is well in excess of the required holding power of the fasteners and indicates that the aged and previously wetted 18 gauge deck is sufficiently robust.

The insulation specimens removed from the test cuts were sent to the laboratory of one of the project participants. Measurements of compressive resistance and R-value were

Specimen	Compressive resistance at 10%, kPa (psi)		R-value per inch, m °K/W(hr ft^2 °F/BTU-in.)	
	As Received	Dried	As Received	Dried
Perlite (22/27)	214 (31.0)	190 (27.6)	14.6 (2.10)	17.1 (2.47)
PIR (22/27)			40.7 (5.87)	43.5 (6.28)
Perlite (52/37)	288 (41.8)	321 (46.5)	16.1 (2.32)	16.9 (2.43)
PIR (52/37)	163 (23.6)	---	41.7 (6.02)	44.2 (6.37)
Perlite (17/37)	94.5 (13.7)	134 (19.5)	12.3 (1.78)	17.9 (2.58)
WFB (17/37)	---	---	33.0 (2.67)	21.4 (3.08)
Perlite (42/107)	358 (51.9)	291 (42.2)	16.3 (2.35)	52.1 (2.44)
PIR (42/107)	---	---	39.5 (5.69)	42.9 (6.19)
Perlite (72/97)	286 (41.5)	260 (37.7)	16.4 (2.37)	17.0 (2.45)
WFB (72/97)	---	---	19.9 (2.87)	53.0 (3.12)
Perlite (22/67)	84.1 (12.2)	108 (15.6)	---	---
PIR (22/67)	---	---	40.0 (5.77)	6.07 (42.1)
Perlite (12/102)	130 (18.9)	73.1 (10.6)	---	---
WFB (12/102)	127 (18.4)	---	18.9 (2.73)	21.3 (3.07)

Table 1: Thermophysical properties of existing and re-cover insulation materials twelve months after reroofing.

performed prior to and after drying the specimens to constant weight. These results are presented in *Table 1*. The specimens of the re-cover membrane removed from the test cuts were forwarded to another participant's laboratory to assess their solar reflectance; results from these tests are summarized in *Table 2*.

To successfully re-cover an existing roof, the existing insulation material must be capable of providing a rigid, stable base for the reroofing system. A measure of the existing insulation's capability to provide a satisfactory base is the compressive resistance of the insulation. There is no consensus standard on what percentage of initial properties is required to consider that insulation can be reused [2]. The average compressive resistance of the perlite specimens containing appreciable amounts of water (17/37, 22/67, and 12/102) is 103 kPa (14.9 psi). After drying, the average compressive resistance of these specimens was 105 kPa (15.2 psi). Similarly, the average compressive strength of specimens removed from "dry" locations before and after drying was 286 and 265 kPa (41.6 and 38.5 psi), respectively. Water clearly degrades the compressive properties of the perlite insulation; even after drying, the compressive strength does not approach the values of the specimens removed from "dry" areas. Without existing standards or industry consensus, it is unclear whether the wet WFB has maintained adequate mechanical strength to support a roof re-cover.

The SPRI Re-cover Subcommittee has published recommended guidelines to assess the suitability of a roofing system for re-cover. They state that "unless otherwise recommended by the insulation and membrane manufacturer, insulation that has a compressive resistance of less than 100 kPa (15 psi) for mechanically-attached re-cover systems or 70 kPa (10 psi) for ballasted re-cover systems should be removed and replaced with new insulation" [3]. If this guideline had been followed, perlite insulation located near Grid 12/102 should have been replaced prior to reroofing.

ASTM C-0728-97, Standard Specification for "Perlite Thermal Insulation Board [4]," specifies a minimum R-value requirement for perlite roof insulation of 19.0 m K/W (2.73 hr ft^2 F/Btu-in.). The average "as-received" R-values for the wet and dry perlite locations are 12.3 and 15.8 m K/W (1.8 and 2.3 hr ft^2 F/Btu-in.), respectively. After drying, these R-values increase to 17.8 and 17.3 m K/W (2.6 and 2.5 hr ft^2 F/Btu), respectively. After drying, the perlite insulation R-values are within 10 percent of the ASTM requirements indicating that thermal performance loss due to having been wet is not a permanent or significant problem.

The solar reflectance of the white membranes from Manufacturers 1 and 2 decreased from 0.82 and 0.78 to 0.71 and 0.67, respectively, after being exposed for one year on the test roof. When the membranes were cleaned, the solar reflectance increased to 0.82 and 0.76, respectively. The data suggest that the reductions in solar reflectance are primarily due to dirt buildup. The reflectance of the black membranes has not exhibited any significant changes, maintaining their initial solar reflectances of 0.07 and 0.04+/-0.02 after the twelve-month exposure.

Specimen Age	Solar Reflectance, Percent			
	Black (Mfg. 1)	White (Mfg. 1)	Black (Mfg. 2)	White (Mfg. 2)
New	0.07	0.84	0.04	0.78
90 Days, As Is	0.06	0.75	0.06	0.70
90 Days, Clean	0.06	0.82	0.04	0.76
365 Days, As Is	0.08	0.71	0.05	0.67
365 Days, Clean	0.07	0.82	0.04	0.76

Table 2. Solar reflectance of white and black TPO membrane materials.

Moisture Measurements and Analysis

A major goal of this project was to determine how rapidly the existing roof would dry after it had been re-covered. To assess the drying rate of the roof system, it was essential to accurately determine the initial concentration and distribution of moisture in the existing roof. In June 1998, just after the reroofing, one of the project participants performed a nuclear densometer moisture survey of the entire roof on a grid with nodes 5 ft. (1.5 m) apart. Seven core samples were taken at the same time and were used to calibrate the output of the nuclear densometer.

The relationship between the output of the nuclear densometer and the moisture content of the core samples (determined gravimetrically) was obtained by linearly regressing the data. Coefficients of fit for these regressions exceeded 0.95. Separate relationships were developed for the different re-cover insulation areas; those relationships were then employed to determine the moisture content for each location sampled with the nuclear densometer. The average moisture content for the total roof system was determined by an area-weighted sum. Additionally, area-weighted moisture contents of the roof areas covered by

Roof Area	Average Moisture Content, Weight Percent, After			
	0 Months	4 Months	12 Months	25 Months
Entire Roof	14.2	13.4	11.1	9.0
WFB Re-cover	17.6	16.3	12.8	9.6
PIR Re-cover	10.8	10.5	9.5	8.3
Black Membrane	14.6	13.6	10.8	8.6
White Membrane	13.7	13.1	11.1	9.3

Table 3. Moisture contents of various roof areas as a function of time after roof re-cover.

different re-cover insulations and different membrane colors were also determined.

Nuclear densometer surveys were repeated 4, 12, and 25 months after reroofing. These data are presented in *Table 3*.

A combined heat and mass transfer model [5] was used to predict the drying rate of the re-covered roof system. References [5, 6, 7, 8, and 9] have described, validated, and used this model on low-slope roof systems. The model requires as input the geometry and material properties of the components of the roofing system as well as hourly indoor and climatological data. The instrumentation installed in the roofing system was used to define the hourly exterior roof temperature and the indoor vapor pressure and temperature. Hourly values of the roof surface temperatures and monthly averages of the measured interior conditions are used as inputs for the model.

A comparison of the measured drying data and model predictions for the perlite insulation re-covered with white and black membrane areas are presented in *Figure 3*. The model overpredicts the drying rate of the perlite insulation and does not appear to capture the impact of membrane color. Possible explanations for these variations include the lack of sensitivity of the nuclear densometer at lower levels of moisture content or the permeance of the metal deck. The fact that we are averaging a number of locations that range from relatively dry to saturated and the average is not similar to the sum of the range of moisture contents present certainly contributes to the differences noted. Areas that are already relatively dry will dry no further, and the nuclear densometer will simply detect no change in moisture content for these locations. These areas, averaged with areas that are drying, will yield an average change in moisture content that is less than the situation where all of the locations contain the same (average) amount of moisture.

The model does not predict any significant seasonal variations in the drying rate of the perlite insulation. This result is consistent with our expectations because the wetted insulation layer is relatively protected from seasonal temperature fluctuations by the re-cover insulation. However, the model does a fair job at estimating how long the perlite insulation must be exposed to reach an average moisture content that was less than saturation. The model predicted times ranging from 9-13 months while the test data indicates that 12 months were needed.

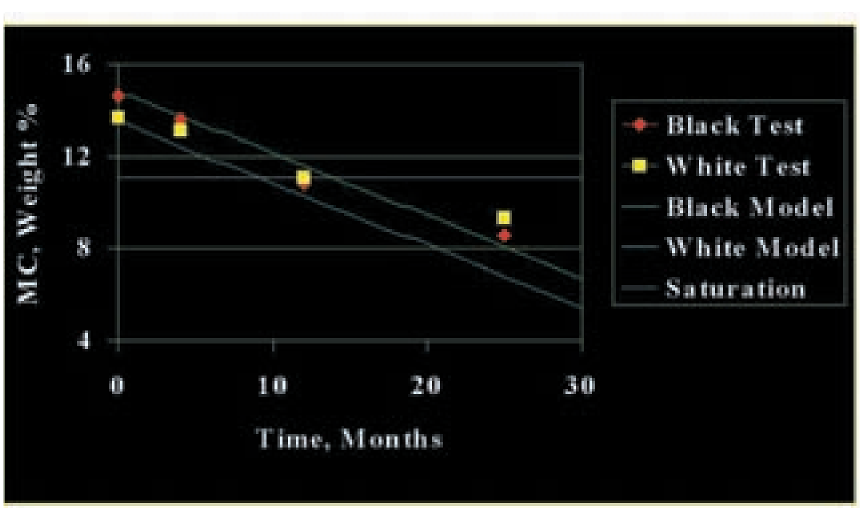

Figure 3. Comparison of measured and modeled moisture contents of perlite insulation.

Conclusions

This full-scale re-cover demonstration project has supplied a significant amount of data regarding the hydrothermal performance of re-cover roofing systems. It complements another re-cover demonstration project in a warmer climate that has been previously reported [10]. The following recommendations have been developed from the work completed thus far:

- The existing roof system cross section should be verified by means of core cuts;
- Core cuts should also be taken from "suspect" areas to determine the extent of damage. If areas of insulation are wet, their ability to support the new roofing system should be analyzed. Unless otherwise recommended by the insulation and membrane manufacturer, insulation, after drying, that has a compressive resistance of less than 100 kPa (15 psi) for mechanically-attached re-cover systems or 70 kPa (10 psi) for ballasted re-cover systems should be removed and replaced with new insulation. The top surface of the structural deck can also be examined from the openings created by the core cuts. If deck corrosion is present, the structural integrity of the deck should be checked (see below);
- The design professional should inspect the deck to determine the extent of replacement or repair required, if any. A complete underside (as well as a topside) examination in questionable areas should be undertaken;
- Fastener pullout tests should be conducted to verify the structural integrity of the deck, regardless of the method of attachment of the re-cover application. This is particularly important when using non-penetrating fasteners that are specifically designed for lightweight decks such as cementitious wood fiber and gypsum;
- The re-cover system should be comprised of materials that will not degrade during the drying interval; and
- The moisture content of the insulation should be measured. Using a simulation tool or an accepted alternate, an estimate of the length of time that is required to dry the insulation should be performed. Insulation that requires

an excessive length of time to dry may create other conditions that lead to roof component failures and should be removed. The length of time to dry varies from roofing system to roofing system. Roofing systems that have been wet for an extended period of time prior to reroofing or contain moisture-sensitive components must be dried more rapidly than roofing systems that have just recently failed or contain moisture-tolerant materials. ■

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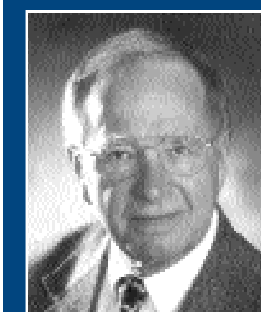
André Desjarlais is Program Manger for the Building Envelope and Materials Research Programs at the Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee. Desjarlais has been involved in materials research for over 25 years, first as a consultant, and for the last nine years with ORNL. He particiates in ASHRAE, ASTM (as an officer), SPRI (as a director and techni cal chairman), RICOWI (as a director), the Federal Roofing Committee (as past chairman), the National Fenestration Rating Council, and the Building Thermal Envelope Coordinating Committee (as a director). His areas of expertise include building envelope and mater ial energy efficiency, moisture control, and durability.



J.P. Sheahan

J.P. Sheahan is a past president of RCI. From 1959 to 1978, Jim gained experience in many facets of the con struction industry—primarily in water proofing and insulation—through his work with Dow Chemical Co. In 1979, he formed J.P. Sheahan & Associates Inc. in Midland, Michigan. He is a Registered Roof Consultant and has been a member of the Cellular Plastics Division of the Society of Plastic Industries (SPI), of CSI, ASTM D-08, and BTECC. Jim holds 15 patents on roof-related products.

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