# THE PEMBROKE PROJECT: A FULL-SCALE DEMONSTRATION OF ROOF RE-COVER

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The debate over re-covering existing wet or damp roofing insulation has been going on for many years. The key issues surrounding this controversy are the drying of wetted insulation, deck deterioration (e.g., dry rot of wood, disintegration of concrete, corrosion of metal), and fastener failures. In 1992, the SPRI Re-cover Subcommittee proposed that an experiment be performed that would generate the data necessary to address these concerns and developed a list of criteria that the ideal test building should possess. In 1994, the Roof Consultants Institute (RCI) identified a building, the Municipal Building in Pembroke, Virginia, that satisfied all of the major criteria developed by SPRI. Representatives of SPRI, RCI, and Oak Ridge National Laboratory (ORNL) visited the building and, with the permission of the town, decided to use this building for their demonstration.

The building was re-covered in April 1995. During reroofing, instrumentation was embedded in the roof system and installed in the building interior to monitor temperatures and relative humidity. The roof has been periodically scanned nondestructively for moisture content. In addition, core samples of the insulation materials and fasteners were removed one year after the roof was re-covered.

This paper describes the building selection, reroofing process, data collection, and nondestructive analyses that have performed to determine if the old roof 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.

**KEYWORDS**

Computer simulation, field testing, moisture, re-cover, reroofing, wet insulation, whole-building.

## INTRODUCTION

Re-covering roofs continues to become an increasingly popular method of reroofing. Project Pinpoint supplies data that shows that re-cover has increased from 11 percent of all roofing activity in 1983 to 22 percent in 1988.[1] The NRCA Annual Market Survey for 1994 indicates that re-cover now represents approximately one-third of all roofing activity.[2]

The same source reports that reroofing now represents over three-quarters of all U.S. low-slope roof construction. The decision of whether to replace or re-cover a roof occurs 75 percent 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 make this everyday decision.

Market forces and environmental issues have clearly led to the increased use of re-cover. Being less expensive than tear-off, re-cover is typically the lower-cost option. 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 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, a means of removing that water in a timely fashion is required. Without the use of specialty re-cover systems that reportedly allow water vapor to migrate through vents or some other similar mechanism, entrapped water must be able to diffuse downward into the building interior.[3] An estimate of the drying rate must be known to determine whether the components of the new and existing roof systems can maintain adequate physical properties to perform properly once the drying has been completed. Furthermore, knowledge of the degradation rate of the roofing components or impact of the moisture on the roofing materials/system is required.

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

A means of determining the correct action is computer simulation. Knowing the amount of moisture contamination, roof system construction, location of the building, and the interior conditions, roof 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 industry has traditionally frowned on the use of these techniques as decision-making tools until they are validated with field experiments.

Recognizing this need, a consortium made up of SPRI and its members, RCI, and ORNL planned, organized, and performed a whole building roof re-cover on the municipal building in Pembroke. This paper represents a progress report on this 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 data necessary to address these concerns and developed a list of 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 of the reroofing. Ideally, the building should be between 278 and 929 m² (3,000 and 10,000 square feet).
- 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 the research team to perform an experiment on the building.
- Ideally, the building should be owned by an nonprofit organization that would benefit from the reroofing project.

In August 1994, a member of RCI identified a building, the Municipal Building in Pembroke, that appeared to satisfy most of the major criteria developed by SPRI. The building is pictured in Figure 1. The building was a one- and two-story structure that served as the town's fire station, police station, and town hall. The building had two roof planes and a total roof area of 380 m² (4,120 square feet). One roof plane (the lower roof) was located over a garage used to house the volunteer fire station and was approximately 195 m² (2120 square feet). This portion of the building was heated but not air-conditioned. The second roof plane (the upper roof) was 185 m² (2,000 square feet) and covered the hall and office area and were conditioned year-round.

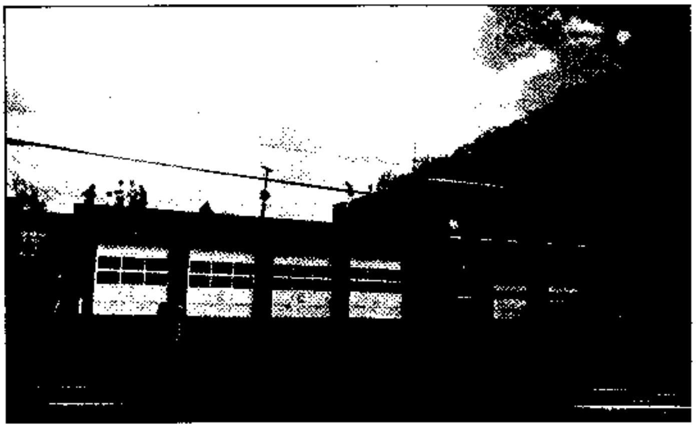

*Figure 1. The Pembroke Municipal Building as seen from the south. The two roof planes over the fire department (left) and offices (right) are shown in this photo.*

The roof was composed of an aggregate-surfaced four-ply organic felt asphalt BUR over 51-mm- (2-inch-) thick wood fiberboard (WFB) insulation spot mopped to a 22-gauge manufacturer-primed Type-B metal deck. The building owner informed the authors that the roof was approximately 27 years old and had been leaking for over 10 years. Numerous temporary repairs apparently never solved the leakage problem, and the town was financially incapable of replacing the roof.

Representatives of SPRI, RCI, and ORNL visited the building in December 1994. During that visit, they met with town officials to discuss the research team's interest in their building, to assess their willingness in participating in the project, and to examine the roof system. They performed a visual inspection of the roof and underside of the deck, took several core samples to verify the roof components and the absence of a vapor retarder and to determine the amount of moisture in the roof system, and performed fastener pullout tests to use as an indicator of the condition of the metal deck. Shortly after the visit, a nuclear densimeter moisture survey was performed on the roof to determine the extent of moisture contamination.

In summary, the roof system satisfied most of the criteria. The authors had hoped for a more northern location and possibly more extensive moisture in the roof. But given that they had been searching for a suitable building for more than two years and the town had granted its permission, the authors decided to use this building for the demonstration project.

## THE REROOFING

The reroofing was performed during the first week of April 1995. After brooming off any loose aggregate, 13- and 76-mm- (0.5- and 3-inch-) thick extruded polystyrene (XEPS) foam were mechanically attached to the lower and upper roofs, respectively, using fasteners with a compliance-grade base coating that meets the minimum requirements of FM

4470. On each roof plane, approximately half of the roof area was covered with a black or white ethylene/propylene-based single-ply membrane. The membranes were installed using a mechanical attachment design similar to that needed to resist wind uplift of 2.9 kPa (60 PSF). The flashings were totally redone, and the existing stone copings were covered with a metal coping.

The authors decided to reroof this building in the manner previously described because of their interest in examining the effects of roof color and re-cover insulation thickness on the drying rate of the roof system. The black and white ethylene/propylene membrane had as-installed solar reflectances of 0.06 and 0.82, respectively. These values of solar reflectance approximate the limits of membrane color used in roofing applications. When re-covering a roof 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. The authors attempted to capture these two extremes with the two thicknesses of XEPS insulation that were installed.

Because the authors were interested in modeling the roof system, instrumentation was installed in the roof system during the reroofing. Temperature sensors were installed just under the membrane, and temperature and relative humidity sensors were installed below the deck of each roof plane. 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 roof system while the sensors below the deck would monitor the indoor conditions. Figure 2 depicts the layout of the re-cover system and the location of the instrumentation installed in the roof system.

All of the instrumentation was connected to a data acquisition system (DAS) that was 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.

## FIELD SAMPLING ONE YEAR AFTER THE REROOFING

In early June 1996, members of the research team returned to Pembroke to perform core cuts on the re-covered roof system. The roof was marked off in a grid pattern on 1.5-m (5-foot) centers, and sampling was performed at the intersection of the gridlines. Gridlines running in a north-south direction were numerical designation (1 through 19) with the most westerly gridline designated as *1*. Gridlines running in a east-west direction were designated with a letter (A through G) with Line *A* on the north side of the building. Sites A1 through G10 were on the lower roof, and sites A11 through G19 were on the upper roof.

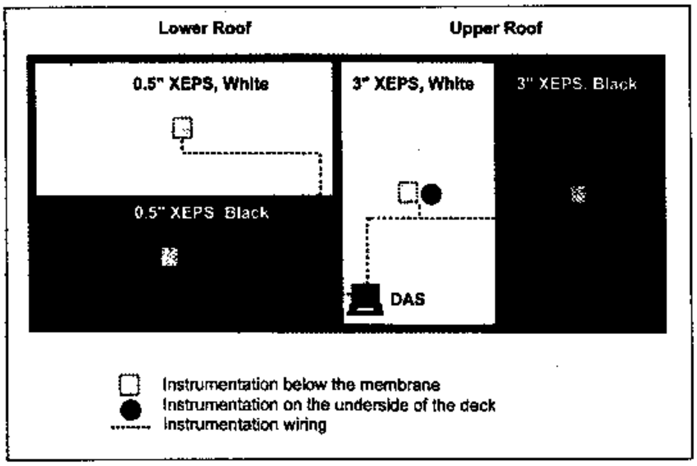

*Figure 2. A schematic of the membrane and instrumentation layout employed on the Pembroke Municipal Building. Each roof plane was bisected and re-covered with a black and white single-ply membrane. Instrumentation was installed in the roof system to monitor the exterior membrane surface temperature and the building interior temperature and humidity.*

Seven sites were selected for sampling. At each site, a 600-mm (24-inch) square cutout was made in the re-cover membrane and XEPS foam. After verifying that the fasteners were tight, the fastener plates were cut off and foam around the fastener was cut away so that a fastener withdrawal test could be performed. After pullout of the existing fasteners, a 300-mm (12-inch) square section was cut out of the BUR and existing fiberboard insulation. Specimens of the XEPS, fiberboard, and membrane were coded, placed into plastic bags, and shipped to test laboratories for subsequent testing. New fasteners were installed into the deck and pullout tests performed as an indicator of the deck s integrity. Fastener pullout test results are presented in Table 1. Observations made at each of the sites are listed below.

- G5—This site was used simply to develop the correct sample removal techniques. It is located on the lower roof under the black membrane and was expected to be relatively dry. The surface of the deck appeared slightly corroded, and there was no visual indication of moisture.
- C5—Located under the white membrane on the lower roof, this area was dry, but the deck was more heavily corroded than G5. There was no visible indication of moisture present.
- B2—Located under the white membrane on the lower roof, this area was expected to be wet. There was an indication of a small amount of moisture under the re-cover membrane. Significant fastener corrosion was noted at this location. The fiberboard insulation was saturated.
- A4, A7, and A9—All located under the white membrane on the lower roof, these areas were expected to be very wet. The fiberboard ranged from saturated at A4 and A7 to relatively wet at A9. Some fasteners were loose in these areas.
- A15—Located under the white membrane on the upper roof, this area was expected to be dry. No moisture was noted during specimen removal, and the deck appeared

| Location | Existing Fastener Pullout | | New Fastener Pullout | |
|---|---|---|---|---|
| | lbs | N | lbs | N |
| A4 | 140 (2) | 625 | 280 (2) | 1250 |
| A7 | 315 (3) | 1400 | 325 (1) | 1450 |
| A9 | 325 (2) | 1440 | 350 (1) | 1560 |
| A15 | 570 (1) | 2540 | 380 (1) | 1690 |
| B2 | 160 (3) | 710 | 260 (1) | 1160 |
| C5 | 450 (2) | 2000 | 195 (3) | 870 |
| G5 | 480 (2) | 2140 | No Data | No Data |

*Table 1. Fastener pullout test data. The number in parentheses indicates the number of fasteners tested at each location.*

to be in better condition than the lower roof deck with no visible corrosion present.

The insulation specimens removed from the test cuts were sent to the laboratory of one of the project participants. Measurements of density, compressive strength, and R-value were performed prior to and after drying the specimens to constant weight. From these measurements, the moisture contents were also determined. These results are presented in Table 2. The specimens of membrane removed from the test cuts were forwarded to another participant's laboratory to assess their solar reflectivity; results from these tests are summarized in Table 3.

In the areas of high moisture content (A4, B2, and A7), the average pullout strength of the existing fasteners was reduced to an average of 960 N (215 pounds) when compared to the average pullout strength of approximately 1960 N (440 pounds) from fasteners removed from dry areas. The fasteners in the wet locations were severely corroded and, in some instances could be easily removed from the deck by hand. The fasteners that the research team had used in the original installation of the re-cover system had been chosen for their minimum corrosion resistance and had only a base coating. However, this coating passed a 15-cycle exposure in the 2.0-L Kesternick cabinet when tested in accordance with DIN 50018, met the minimum requirements of FM 4470 and could be specified for re-cover applications. There are many other fasteners presently available that have four times the corrosion resistance when tested in a similar manner; the performance of fasteners with greater corrosion protection will be discussed later in this paper.

Results from the new fasteners installed to check the deck integrity are somewhat masked by fact that some earlier leaks had been successfully repaired. In particular, the deck in location C5 appeared to be quite corroded, yet there was no moisture present during sampling. Ignoring this location, the average pullout strength of new fasteners installed in wet and dry areas was 1290 and 1600 N (290 and 360 pounds), respectively. Variation in all of the fastener pullout test results is probably due to the variable condition of the deck and the typical scatter seen when performing this type of experiment. With the exception of location C5, there appeared to be a correlation between insulation moisture content and deck corrosion. Areas that had higher moisture content show reduced fastener pullout loads.

The moisture content of the wood fiberboard (WFB) ranged from 246 to 5 weight percent (at saturation, the moisture content of WFB is approximately 30 to 36 weight percent[4, 5]). Locations A4, A7, A9, and B2 have WFB insulation above saturation (WFB contains liquid). The XEPS insulation had moisture contents ranging from 0.4 to 2.2 weight percent. Because XEPS has a saturation moisture content of approximately 5 weight percent,[4] only water vapor is present in the XEPS.

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 of providing a satisfactory base is the compressive strength of the insulation. ASTM C 0208-95, "Standard Specification for *Cellulosic Insulating Board*" does not require compressive property measurement of wood fiberboard roofing insulations.[6] Furthermore, there is no consensus standard on what percentage of initial properties are required to consider that an insulation can be reused.[7] The average compressive strength of the WFB specimens containing water is 26.9 kPa (3.9 psi). After drying, the average compressive strength of specimens removed from the wet locations increased to 77.2 kPa (11.2 psi). Similarly, the average compressive strength of specimens removed from dry locations before and after drying was 172 and 181 kPa (24.9 and 26.2 psi), respectively. Water clearly degrades the compressive properties of the WFB; even after drying, the compressive strength does not approach the values of the specimens removed from a dry area. Without existing standards or industry consensus, it is unclear whether the wet WFB has maintained adequate mechanical strength to support a roof re-cover.

ASTM C 0578-95, "Standard Specification for *Rigid, Cellu-*

| | Density, pcf (kg/m³) | | Compressive Strength @ 10%, psi (kPa) | | R-value per inch, hr ft2°F/Btu-in. (m °K/W) | | Moisture Content, |
|---|---|---|---|---|---|---|---|
| **Specimen** | **As Received** | **Dried** | **As Received** | **Dried** | **As Received** | **Dried** | **Weight %** |
| WFB (A4) | 27.5 (441) | 13.1 (210) | 2.5 (17.2) | 13.2 (90.4) | 0.6 (4.2) | 2.4 (16.6) | 264 |
| WFB (A7) | 17.8 (285) | 11.4 (183) | 4.1 (28.2) | 10.5 (72.3) | 1.0 (6.9) | 2.1 (14.6) | 85 |
| WFB (A9) | 16.8 (269) | 14.0 (224) | 6.3 (43.4) | 19.3 (133) | 1.2 (8.3) | 2.3 (15.9) | 57 |
| WFB (B2) | 35.8 (574) | 12.5 (200) | 2.6 (17.9) | 11.8 (81.3) | 0.9 (6.2) | 2.2 (15.2) | 246 |
| WFB (C5) | 14.8 (237) | 15.1 (242) | 24.7 (170) | 27.1 (187) | 2.4 (16.6) | 2.6 (18.0) | 5 |
| WFB (G5) | 15.0 (240) | 15.2 (244) | 26.7 (184) | 25.7 (177) | 2.5 (17.3) | 2.5 (17.3) | 5 |
| WFB (A15) | 14.8 (237) | 14.9 (239) | 23.2 (160) | 26.0 (179) | 2.4 (16.6) | 2.4 (16.6) | 7 |
| XEPS (A4) | 2.13 (34.1) | 1.96 (31.4) | 18.4 (127) | 18.2 (125) | 4.8 (33.3) | 4.8 (33.3) | 2.2 |
| XEPS (A7) | 1.96 (31.4) | 1.97 (31.6) | 17.3 (119) | 18.4 (127) | 4.8 (33.3) | 4.8 (33.3) | 0.7 |
| XEPS (A9) | 1.95 (31.2) | 1.99 (31.9) | 17.1 (118) | 18.5 (127) | 4.8 (33.3) | 4.6 (31.9) | 0.5 |
| XEPS (B2) | 1.89 (30.3) | 1.92 (30.8) | 19.4 (134) | 20.1 (138) | 4.8 (33.3) | 4.8 (33.3) | 0.9 |
| XEPS (C5) | 1.87 (30.0) | 1.89 (30.3) | 14.8 (102) | 16.6 (114) | 4.8 (33.3) | 4.8 (33.3) | 0.5 |
| XEPS (G5) | 1.84 (29.5) | 1.82 (29.2) | 20.0 (138) | 18.7 (129) | 5.0 (34.7) | 5.0 (34.7) | 0.4 |
| XEPS (A15) | 1.62 (26.0) | 1.56 (25.0) | 33.4 (230) | 31.6 (218) | 5.1 (35.4) | 5.1 (35.4) | 1.1 |

*Table 2. Thermophysical properties of insulation materials 14 months after reroofing.*

| Specimen | Condition | Reflectance |
|---|---|---|
| White | New | 0.82 |
| White (A4) | 14 Months | 0.55 |
| White (A7) | 14 Months | 0.50 |
| White (A9) | 14 Months | 0.60 |
| White (A15) | 14 Months | 0.61 |
| White (B2) | 14 Months | 0.68 |
| White (C5) | 14 Months | 0.63 |
| White (A7) | 14 Months, Washed | 0.76 |
| Black | New | 0.06 |
| Black (G5) | 14 Months | 0.06 |
| Black (D17) | 14 Months | 0.06 |

*Table 3. Solar reflectance of white and black ethylene/propylene membrane materials.*

*lar Polystyrene Thermal Insulation*," does include a compressive strength requirement for XEPS foam.[8] Type VI foam requires a minimum compressive strength of 276 kPa (40 psi). The average compressive strengths measured on the as-received 13- and 38-mm- (0.5- and 1.5-inch-) thick XEPS foam specimens were 123 and 230 kPa (17.8 and 33.4 psi), respectively. The specimens were badly pitted by aggregate from the BUR, causing the compressive strength values to be lower than expected and impacting the test results. These imprints in the foam invalidate the comparison between the field test results and the material specification.

ASTM C 0208 and C 0578 specify minimum R-value per inch requirements for WFB and XEPS of 18.0 and 34.4 m °K/W (2.6 and 5.00 hr ft$^2$ °F/Btu-in.), respectively. The average as-received R-values for the wet and dry WFB locations are 6.9 and 16.6 m °K/W (1.0 and 2.4 hr ft$^2$ °F/Btu-in.), respectively; after drying, these R-values increase to 15.6 and 17.3 m °K/W (2.2 and 2.5 hr ft$^2$ °F/Btu), respectively. The XEPS foams closely match ASTM requirements; the as-received R-values for the two thicknesses are 33.3 and 35.4 m °K/W (4.8 and 5.1 hr ft$^2$ °F/Btu-in.). Because the foam has little moisture, drying has a negligible impact on its thermal performance. In addition, the mechanical damage caused by the aggregate penetrating the surfaces of the XEPS apparently does not appreciably degrade its thermal performance.

Reference 7 suggests that industry members participating in a survey would allow a 25 percent reduction in R-value and still allow the insulation to be reused. Given this criterion, the WFB insulation could be considered for reuse. Tobiasson has suggested that if the insulation R-value has been reduced by more than 20 percent, the insulation is unacceptable because of its loss of insulating ability.[9] The WFB has lost approximately 60 percent of its R-value but if the insulation can dry, the loss is reduced to 15 percent. If the insulation can be dried, Tobiasson's 80 percent TRR (thermal resistance ratio) would be satisfied and the WFD could be reused.

The solar reflectance of the white membrane decreased from 0.82 to an average of 0.60 after being exposed for fourteen months on the test roof. One of the membrane specimens (A7) was washed and subsequent testing yielded a reflectance 0.76. The data suggests that the reduction in solar reflectance is due to both membrane changes as well as dirt buildup. The reflectance of the black membrane has not exhibited any changes, maintaining its initial solar reflectance of 0.06 after the 14-month exposure.

## MOISTURE MEASUREMENTS AND ANALYSIS

A major goal of this project was to determine whether or not the existing roof would dry after it had been re-covered. Therefore, a series of field measurements were performed, the instrumentation was installed in the roof system and building, and samples of the roof system were removed for laboratory testing.

To assess whether the roof system would dry, it was essential to accurately determine the initial concentration and distribution of moisture in the existing roof. In April 1995, just prior to the reroofing, one of the project participants performed a nuclear densimeter moisture survey of the entire roof on a grid with nodes 1.5 m (5 feet) apart. A second survey was performed in August 1995. The authors attempted to correlate the results of this survey with core sampling that was taken just prior to the reroofing but discovered that there was sufficient uncertainty in the coring locations to warrant a more detailed second round of core sampling. In the meantime, the authors' access to this nuclear densimeter became limited, and they chose to use a second nuclear densimeter that was more readily available to the project team. The roof has been surveyed three times with the second gauge: in April 1996, June 1996, and February 1997. The June 1996 nuclear densimeter results were correlated with the core sampling data that was compiled at the same time. The relationship between the output of the nuclear densimeter and the moisture content of the core samples (determined gravimetrically) was obtained by linearly regressing the data and using that relationship to determine the moisture content for each location sampled with the nuclear densimeter. The total roof system moisture content was determined by an area weighted sum. Because this relationship is dependent on the nuclear densimeter used, the nuclear densimeter data compiled with the initial gauge could not be analyzed any further and unfortunately cannot be used. Therefore, all of the moisture analyses effectively start in April 1996.

The authors found that the nuclear densimeter was not very sensitive to moisture content on the upper roof, and they expect that the difficulty encountered was due to the upper roof assembly not containing any areas that were very wet, which makes calibrating the nuclear densimeter difficult because of the limited range of output data. Secondly, the thickness of the re-cover insulation on this roof plane is 76 mm (3 inches), and the authors suspect that this is adding to the difficulty of calibrating the gauge. Given that the upper roof is relatively dry, the research team concentrated on studying the lower roof assembly.

In April 1996, the researchers determined that the lower roof had average moisture contents under the black and white membranes of 33 and 102 weight percent, respectively. Subsequent nuclear densimeter surveys have been analyzed in a similar manner.

A combined heat and mass transfer model[10] was used to predict the drying rate of the re-covered roof system. References 10, 11, 12, 13, and 14 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 roof system, as well as hourly indoor and climatological data. The instrumentation installed in the roof system was used to define the hourly exterior roof temperature and the indoor vapor pressure and temperature. Figure 3 depicts the hourly and monthly average indoor vapor pres-

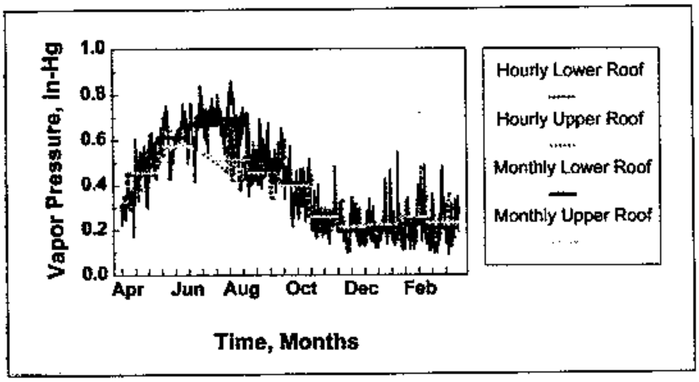

*Figure 3. The hourly and monthly average vapor pressures under the lower and upper roofs of the Pembroke Municipal Building. The monthly averages were used as input to the simulation model.*

sures under the lower and upper roof systems for the time period between April 1995 and April 1996. Monthly averages are used as inputs for the model.

A comparison of the actual drying data and model predictions is presented in Figure 4. The model overpredicts the moisture content data calculated from the nuclear densimeter surveys by about 10 weight percent for the white membrane portion of the lower roof. This difference is equivalent to one count on the nuclear densimeter. Other possible reasons for this difference are some leakage into the building, air flow in the flutes of the deck, or higher permeability of the metal deck than was modeled. For the black membrane portion of the lower roof, the model agrees well with the first set of nuclear densimeter data but underpredicts the moisture content (or overpredicts the drying rate) of the second set of nuclear densimeter data by approximately 15 weight percent. Possible explanations for this variation include the sensitivity of the nuclear densimeter at lower levels of moisture content, the permeance of the metal deck, or the fact that the research team is averaging a number of locations that range from relatively dry to saturated, and the average is not similar to sum of the range of moisture contents present. Areas that are already relatively dry will dry no further and the nuclear densimeter 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. Additional data are needed to ascertain the cause of the differences noted between the modeled and measured levels of moisture content remaining in the roof; this data will be gathered during future visits to the building.

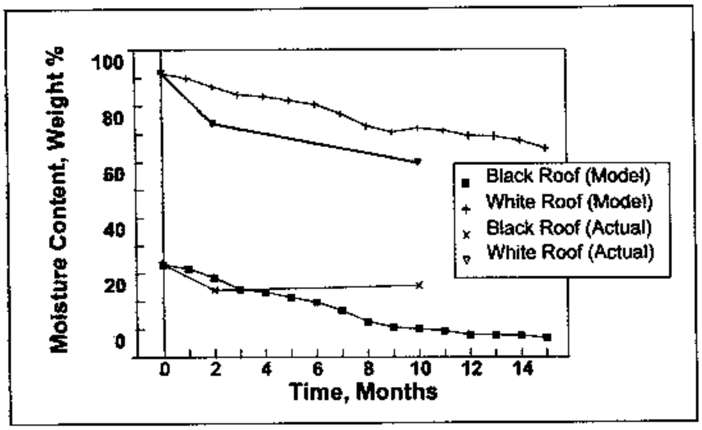

*Figure 4. The measured and simulated moisture contents of the black and white membrane portions of the lower roof of the Pembroke Municipal Building. Time 0 is April 1996. See text for further details.*

The model does not predict any significant seasonal variations in the drying rate of the roof system. This result is consistent with the authors' expectations because the wetted insulation layer is relatively protected from seasonal temperature fluctuations by the re-cover insulation.

## CONCLUSIONS

This full-scale re-cover demonstration project has supplied a significant amount of data regarding the performance of this reroofing system. This project is ongoing; the authors expect to revisit the roof yearly to gather additional data. The following findings have been developed from the work completed thus far:

- The reroofing of the Pembroke Municipal Building has solved the building owners' short-term requirements of making the roof system weather tight. No leaks have been reported since the re-cover was performed in April 1995.
- Fasteners with base coatings that meet the minimum requirements of FM 4470 appear to be insufficiently protected when reroofing over wetted wood fiberboard insulation. Appreciable corrosion of the fasteners has been found after just one year of service.
- The re-cover system is functioning properly after one year of service. No moisture has been detected in the re-cover insulation material, and the XEPS has maintained its thermal efficiency.
- The wood fiberboard insulation contained a wide range of moisture. The thermal performance and the compressive properties were significantly reduced because of this contamination. Upon drying, these properties increased but not to their original levels. Criteria for reuse is unavailable and is sorely needed.
- The solar reflectance of the white membrane decreased with time and improved when cleaned. The black membrane has not exhibited any changes in solar reflectance after one year of exposure.
- The original roof system is drying. A computer model used to simulate the moisture performance of the roof system underestimates the drying of the wet insulation under the white membrane and overestimates the drying of the damp insulation under the black membrane. The reason for variances between the experimental and modeling data are under investigation, and hypotheses are offered.
- Pass/fail criteria are needed to determine whether insulation materials can provide an adequate substrate for a re-cover roof system. With these criteria, protocols to assess the advisability of roof re-cover can be developed.

## FUTURE WORK

The re-cover roof system installed on the Pembroke Municipal Building will continue to be monitored. Presently, yearly visits to the building are planned for inspection and sampling purposes.

The issue of fastener corrosion is being studied further; four different types of fasteners having greater corrosion resistance than the original fasteners were installed in the wet portion of the roof in October 1996 and will be monitored for their corrosion resistance over the next several years.

The moisture concentration within the roof system will also be monitored. Several additional moisture surveys are planned, along with a detailed inspection of the decking system to try to determine the differences noted between the modeling and the moisture surveys.

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