The Effects of Roof Membrane Color on Moisture Accumulation in Low-slope Commercial Roof Systems

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Agenda

• Background
• SPRI Field Study
• SPRI/ORNL Roof Drying Study
• WUFI Analysis
• Conclusions and Recommendations for Future Work
• Black membranes are typically 50F warmer than white membranes on a sunny day

• Theorized impact
  – Location/occurrence of dewpoint
  – Impact ability of system to dry out
Dewpoint calculation

• Must consider:
  – Interior and Exterior Temperature and RH
  – The R-value and water vapor permeability of the components of the roof assembly
  – Potential for direct air movement through the assembly
  – Compare dewpoint with actual conditions at each layer
Common dewpoint calculation

### Conditions:

<table>
<thead>
<tr>
<th></th>
<th>Interior</th>
<th>Exterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>72.0</td>
<td>34.0</td>
</tr>
<tr>
<td>Humidity</td>
<td>35</td>
<td>80</td>
</tr>
</tbody>
</table>

### Dewpoint Theory

Dewpoint Theory predicts condensation in a system at any point where the actual and dewpoint temperature lines cross.

### Table

<table>
<thead>
<tr>
<th>Component Name</th>
<th>Thickness (in)</th>
<th>R-Value</th>
<th>Rep</th>
</tr>
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<tbody>
<tr>
<td>A Interior Air Film</td>
<td>0.10</td>
<td>0.68</td>
<td>0.001</td>
</tr>
<tr>
<td>B Metal Deck</td>
<td>2.00</td>
<td>0.10</td>
<td>0.100</td>
</tr>
<tr>
<td>C GYPSUM.625in</td>
<td>0.625</td>
<td>0.56</td>
<td>0.023</td>
</tr>
<tr>
<td>D DECKMATE Plus Insulation</td>
<td>2.000</td>
<td>10.00</td>
<td>2.000</td>
</tr>
<tr>
<td>E Out Air Film Winter</td>
<td>0.100</td>
<td>0.17</td>
<td>0.001</td>
</tr>
</tbody>
</table>

### Interface Table

<table>
<thead>
<tr>
<th>Interface</th>
<th>Temperature</th>
<th>Dewpt</th>
<th>Accum (utility-net)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-A</td>
<td>72.00</td>
<td>42.88</td>
<td>0.000</td>
</tr>
<tr>
<td>AB</td>
<td>69.75</td>
<td>42.88</td>
<td>0.000</td>
</tr>
<tr>
<td>BC</td>
<td>69.42</td>
<td>42.33</td>
<td>0.000</td>
</tr>
<tr>
<td>CD</td>
<td>67.58</td>
<td>42.20</td>
<td>0.000</td>
</tr>
<tr>
<td>DE</td>
<td>34.56</td>
<td>28.91</td>
<td>0.000</td>
</tr>
<tr>
<td>EF</td>
<td>34.00</td>
<td>28.90</td>
<td>0.000</td>
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<td>FG</td>
<td></td>
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<td>GH</td>
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<td>HI</td>
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<tr>
<td>JK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>4825</td>
<td>4454</td>
<td>2475</td>
</tr>
</tbody>
</table>
The objective was to examine roof systems using highly reflective roof membranes in heating climates by cutting into the roof systems and examining them for moisture accumulation.
SPRI Field Study Protocol

- Heating climate
- Test cuts during winter
- Test cuts before 10:30
- Single layer of insulation
- Mechanically attached system
- No vapor retarder
- Roof system in place for at least 5 years
- The building must be climate-controlled
SPRI Field Study Results

- Ten roof systems were investigated.
- In seven of the cases, no moisture or damage to the polyisocyanurate foam insulation or facer was noted.
- In three of the cases, condensation was apparent on the back side of the highly reflective membrane.
  - The level of condensation as described by the observer was “damp” to “wet.”
  - Minimal damage had occurred to the polyisocyanurate foam insulation.
  - Consequential impact was limited on the facer of the product and described by the observer as “stained,” and in one case “wrinkled,” but still laminated to the insulation.
  - The foam itself was dry, with no rust on the steel roof deck.
SPRI Field Study Results

• The conclusion from this portion of the study is that although there were signs of moisture condensation in three of the 10 roofs observed, minimal effect had occurred to the roofing assembly that would affect its integrity, insulating value or performance. No detrimental effect to the roof system was noted.
Radiation Effects

10-day mean temperatures
Holzkirchen, 2000-2005

Temperature [°C]

Month

horizontal surface, black
horizontal surface, white
outdoor air
Radiation Effects

Holzkirchen: clear day in Oct. 2006

Temperature [°C]

Daytime [h]

-2

0

2

4

6

8

10

12

14

16

18

20

22

24

3

°F

Air temperature

Horizontal white surface
Distance: dew point temperature – air temperature

Consequence: Minor overcooling of exterior surfaces yields condensation.
Radiation Physics

Emittance of a solid surface according to Max Planck

Radiation to a recipient surface (irradiance)

Integral yields
- approx. 1367 W/m² (Solar Const.)
- approx. 230 W/m²
Radiation Physics

Difference, about. 70 W/m² (12 Btu/h ft²) is the reason for night-time overcooling.
Enhanced Radiation Modell has been incorporated into WUFI in 2007

For details please refer to:

WUFI Modelling

Outdoor Conditions
Boston, Albany, Chicago, Cleveland, Detroit

Solar Absorptivity
White Roof: 30%
Black Roof: 90%

Indoor Conditions
ASHRAE 160; Simplified Method

Initial Conditions
80% Equilibrium Moisture Content
1 year calculation; starting in October

Evaluation
Condensate of most exterior 2 mm of Polyisocyanurate
WUFI Results

- All roofs accumulate water during the winter and dry out completely in summer.
- Layer thickness about 0.2 mm (8 mil) in maximum.
- Minor Impact of the climate location/exact insulation thickness.
- Minor correlation between the simulation results and the observations.
WUFI Results

- Generally similar behavior compared to white roofs.
- Maximum Condensation layer thickness only at half; 0.08 mm (3 mil)
WUFI Modelling

Uplift of the exterior membrane, due to wind pressure.

Hence, air infiltration from indoor trough joints, nail holes.

Estimated air change rate of 5 [1/h].
WUFI Results

- 3 times more condensate 0.6 mm (24 mil) in maximum.
- Accumulating condensate.
WUFI Results

Black Roof and Air Infiltration Indoor

- Apparently no problem
Simulation Conclusion

- White Surfaces on flat roofs increase moisture content
- In Combination with Indoor Air Infiltration moisture accumulation/damage are more likely

Further Investigation required

- For Climate Zones 6, 7 and 8
- About the amount of Indoor Air Infiltration
SPRI/ORNL Roof Recover Drying Rate Study

• The size of the building was large enough to represent a typical building but small enough to control the cost. (between 3,000 and 10,000 square feet).
• The building was located in a northern climate (CZ5) and had a conditioned interior.
• The roof system was contaminated with an appreciable amount of water.
• The roof system had the potential to dry downwardly (no vapor retarder).
• The roof system was “typical” —i.e., had a metal deck, some insulation and a traditional membrane.
• The deck was structurally sound.
Test layout

• About half the roof area was covered with a black or white mechanically attached TPO single-ply membrane.

• Instrumentation was installed in the roof system during the reroofing. Six temperature sensors were installed directly under the membrane and two sets of temperature and relative humidity sensors were installed inside the building.
Drying rate

• A major goal of this project was to determine how rapidly the existing roof system would dry after it had been re-covered.

• To assess the roof system’s drying rate, it was essential to accurately determine the initial concentration and distribution of moisture in the existing roof system.

• To accomplish this, a nuclear densometer moisture survey of the entire roof on a grid with nodes 5 feet (1.5 m) apart was completed.

• Seven core samples were taken at the same time and were used to calibrate the output of the nuclear densometer.
Drying rate results

The black membrane side dried at a slightly greater rate. (6 percent by weight vs. 4.4 percent by weight.)

This difference in drying rate did not affect the performance of the fasteners or insulation over the two-year period of the study.
Overall conclusions and future work

• Situations where moisture accumulation occurs are design issues.
• When designing a roof system membrane color, in addition to other variables such as building conditions, insulation levels and local weather conditions must be considered in order to prevent moisture condensation and subsequent accumulation within the assembly.
• Within the parameters used in this study, roof systems with white membranes and those with black membranes both went through wetting and drying periods throughout the year, with both systems returning to a dry state during the course of the year.
• Modeling using transient moisture models such as WUFI can and should be used by design professionals to assess the tendency of various roof designs to allow for.
• It is recommended that further investigation should be conducted in climate zones 6, 7 and 8.
• It is also recommended that the effect of possible ventilation effects due to wind pressure and hence uplift of the exterior membrane be investigated.