Sea Change Coming!
HYGROTHERMAL ANALYSIS:
THE NEW DESIGN STANDARD

By Dr. Richard E. Norris, RRC, PE

I looked down at the handful of mush in my hand. It used to be the plywood roof deck. As I gazed at it, I thought, "This could be my design." I wondered how many of my projects, designed over the last few years, could be in comparable condition. A man fell through the roof on a similar building not long ago. Fortunately, the membrane stretched between what was left of the rafters and caught him before he suffered serious injury.

What caused this failure, and why did the designer of the reroofing project not catch it? Why are our buildings self-composting? It was not due to a roof leak. The cause of this failure was the accumulation of water due to condensation. The old roof didn't have this problem. The new roof is a single-ply installed over ¼-in.-thick gypsum board on the old roof deck.

There have been several articles in trade magazines on this subject (Fairnington,[1] Bludau *et al.*,[2] Dregger,[3] and Pierce[4]), and the researchers have been working on it for more than 20 years. Most of the articles focus on cool roofs, but the issue of the accumulation of condensed moisture is not specific to them. I have seen it under cap-sheet-surfaced built-up roofs, too.

As designers, it is our responsibility to prevent condensation from destroying the roof deck (or wall framing). The amount of moisture that condenses in the roof (or wall) assembly must be small enough and the drying forces great enough to prevent liquid water from accumulating in the system. If liquid water remains in the roof deck for sufficiently long, fungus grows and steel rusts.

This is a very complicated dynamic condition—actually two interdependent conditions. Heat flows from hot to cold, and moisture vapor flows from high to low relative humidity. Neither flow is static. Both flows meet resistance in the building envelope system materials. But the resistance to heat flow and that to moisture vapor flow may be very different in the same material. Think of fiberglass batt insulation that is a good insulator but allows moisture to flow freely. To this already complicated condition, we add movement of liquid moisture due to condensation (or leakage). And then we also add differential pressure across the building envelope. It is difficult, at best, to model this complex condition.

ANSI/ASHRAE Standard 160-2009, *Design Criteria for Moisture Control in Buildings*, was developed for this purpose. The standard requires the use of a computer model capable of performing certain calculations to simulate the response of a designed wall or roof system to weather conditions that are likely to occur in that location. The only generally available program meeting this requirement today is WUFI (Wärme Und Feuchte Instationär or "Transient Heat and Moisture"). WUFI has been developed through a collaboration between German and American scientists, with the U.S. work being done at the Oak Ridge National Laboratory (ORNL). André Desjarlais, program manager of the Building Envelopes Program at ORNL, manages the U.S. portion of the development of WUFI. He proposed the inclusion of ANSI/ASHRAE Standard 160-2009, by reference, in the next building code cycle. It is likely to become a code requirement, but it is a very useful tool now.

Classes on WUFI are offered throughout the year. I attended a class in Chicago this spring. André Desjarlais likened the instruction to drinking from a fire hose. Even for those of us who have the educational background, have been studying the phenomenon for a while, and who have tried to apply WUFI to real-life situations before attending the class, this seems like an apt analogy.

WUFI is not without its limitations. The material database is limited, although the authors promise to release more data in October of this year. It is sometimes necessary to accept some substitute material data in order to get the calculation to run. Boundary conditions are complicated, and the most accessible model is one-dimensional (a 2-D program is available). However, it is the best available program for hygrothermal (heat and moisture flow) modeling of building envelope systems. It has North American building materials and weather data built in, considerably simplifying the data input required for running the program.

As powerful as it is, the limitations of WUFI create a difficult situation for designers. We have to be able to understand when the results we get are reasonable and when they are not. In order to understand the results and limitations of WUFI, one has to know something of the science behind it.

Thermodynamics is the study of the movement of heat through materials. We need to have a basic understanding of thermodynamics in order to understand the hygrothermal behavior of wall and roof systems. Moisture vapor flow is similar to the flow of heat, at least in the form of the calculations.

COMPLICATION EXAMPLE

There is no steel roof deck in the WUFI material database. The work-around is to assign a boundary condition porosity of 0.7, treating the metal deck as if it had a vapor resistance similar to a layer of paint. ORNL's testing of steel roof decks gives a permeance range from 0.6 to 1.0. If there is any doubt whether the result is sensitive to the value selected, it is prudent to run the simulation at all three values: 0.6, 0.7, and 1.0. If this is the only such compromise, we are done. However, if several similar compromises are necessary for the input of the system data, it may be prudent to run the simulation calculations quite a few times.

Understanding the limitations of WUFI, as with any tool, is the key to its proper use and to correctly interpreting the output. While 95% or more of the designs are simple enough that there probably will be no significant issues, and a single or small number of calculations are sufficient, it is in the other 5% where the issue becomes complicated. Failure of even a small percentage of a company's designs is enough to tie up its key resources in an attempt to resolve the issue, or in litigation. It could also ruin a company's reputation, causing potential clients to seek professional services elsewhere.

Unfortunately for those of us practicing along the West Coast, it is uncommon for there to be insulation above the roof deck. Therefore, the likelihood that condensation will occur increases significantly. Our designs are frequently much more complex, as we try to find solutions that do not require raising the door at the top of the stairwell, replacement of clerestory windows, or similar modifications to the rest of the building—all to allow the addition of insulation "where it belongs" on top of the roof deck.

CONCLUSION

Design of reroofing and significant modifications to wall systems will soon include a hygrothermal analysis. They should do so now. This is the standard of the industry.

This new standard is initiating a sea change in the industry. It is necessary for all building envelope designers and forensic evaluators to have WUFI in their "toolbox." Further, it is imperative that they have a basic understanding of the science behind the hygrothermal analysis. Otherwise, they will not be able to determine the reasonableness of WUFI output, and consequently they will risk failures and the resulting self-composting of the building.

FOOTNOTES

1. Iain Fairnington, "Reducing Condensation in the Roof Space," *Interface*, September 2001.
2. Christian Bludau, Daniel Zirkelback, and Hartwig M. Kunzel, "Condensation Problems in Cool Roofs," *Interface*, August 2009.
3. Phil Dregger, "'Cool' Roofs Cause Condensation – Fact or Fiction?", *Western Roofing*, January-February 2012.
4. Helene Hardy Pierce, "Unintended Consequences! Keeping Alert to Protect Single-Ply Roofs," *Interface*, February 2012.

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