predefined interior conditions. In both cases, the dew point is calculated based on the interior temperature and relative humidity (RH); if the interior surface temperatures drop below the dew point, surface condensation will occur (Figure 8). In scenario A, the modeler must calculate a dew point for each interior temperature and RH combination based on project-specific information supplied by the mechanical engineer. In scenario B, one interior dew point temperature is calculated based on the predefined interior temperature and RH conditions.

When possible, BECs performing condensation analyses should obtain the conditions (temperature, RH, film coefficient) immediately adjacent to the detail being analyzed in lieu of using the mechanical engineer's interior design set point conditions. In the example in Figure 7, the air temperature and RH within approximately 3 in. to 6 in. of the IGU and mullion surfaces are required. The conditions in this near-wall zone may be influenced by radiators, diffusers, window shades, or other geometry, and therefore must be calculated to accurately assess risk. Some cases like large atria, tall windows, etc. might require computational fluid dynamics (CFD) to evaluate the near-component conditions (see film coefficient section below).

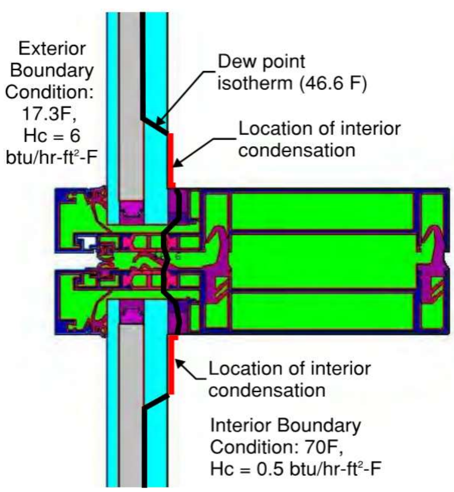

Figure 7 THERM Output Overlaid with Dew Point Isotherm and Locations of Interior Condensation

Temperature Boundary Conditions

In scenario A, the exterior temperature is set to the 99.6% heating design temperature specified in ASHRAE 90.1. Statistically, the 99.6% heating design temperature represents the lowest temperature a region will see for 99.6% of the year, and the exterior temperature to which most mechanical engineers design their heating systems. In this case, it is important for BECs to explain to clients that interior condensation may still occur when exterior temperatures drop below the 99.6% threshold. Depending on the allowable tolerance for condensation, the Design Team may prefer to use a more stringent temperature boundary condition, such as the absolute lowest temperature value based on available historical weather data.

In scenario B, the interior temperature is set to the air temperature within approximately 3 to 6 in. from the surface of the assembly. When the simulation yields an exterior temperature at which condensation occurs, the BEC must then compare that value to available historical weather data to determine anticipated hours of condensation per year.

Film Coefficient Boundary Conditions

The exterior and interior film coefficients typically default to those specified by ASHRAE 90.1 or NFRC 100; however, the modeler may choose to calculate these values or use engineering judgment to make an estimation. The film coefficient defines convective and radiative heat flow at the surface of the geometry and varies with adjacent fluid type (e.g., air) and velocity; therefore, it varies locally across the enclosure and can be difficult to calculate. At the interior, radiation is typically negligible and can be ignored; however, exterior radiation can be important, particularly for sky-facing elements or tall buildings that have a larger view factor to the sky. The exterior film coefficient can be calculated in accordance with ISO Standard 15099.

In cases where the interior air varies in velocity and temperature between its delivery point in the space and the interior surface of the modeled assembly, it is prudent to use a CFD model to calculate the interior film coefficient(s). In this case, the BEC must coordinate closely with the mechanical engineer, the Design Team, and the CFD modeler to obtain and communicate the level of detail required to input into the CFD model. The model must include the general interior layout of the building space and locations of mechanical diffusers, as well as detailed information on interior space conditions (mechanical and natural ventilation, space loads, etc.) and detailed geometry at the interior surface of the building enclosure assembly, among other items.

3.2 Hygrothermal Analysis

Designers rely on personal experience and engineering judgment to determine if hygrothermal analysis of an enclosure assembly is necessary. In doing so, they must consider the project-specific climate, requirements for interior conditions, and location of insulation and vapor barriers within the enclosure assembly, as these factors affect heat and moisture flow. Moisture buildup can lead to material degradation, increased risk of freeze-thaw damage, corrosion, and biological growth.

ASHRAE Standard 160-2016 Criteria for Moisture-Control Design Analysis in Buildings (ASHRAE 160) identifies performance-based criteria for predicting, mitigating, or reducing moisture-related damage to building enclosures. A number of analytic tools meet the procedural criteria within the standard, including a commonly used software program called WUFI. Developed by the Fraunhofer Institute, WUFI is a one-dimensional finite element simulator that calculates transient heat and moisture migration through building materials and assemblies. When using WUFI, the modeler inputs a series of hygrothermal loads, which include initial built-in moisture content of enclosure assembly materials, indoor mechanical conditions, and outdoor climate, among others (Glass et al., 2013).

Material Property Inputs

WUFI has an internally maintained database containing hygrothermal material data sets for a limited set of construction materials. Users can generate custom materials by copying an existing material in the database and inputting basic material data: bulk density, porosity, specific heat capacity, thermal conductivity, and water vapor diffusion resistance. Users can also input built-in moisture (pcf), if material-specific data is known. For absorptive materials (e.g., brick masonry) or variable permeance materials, it may be necessary to input hygrothermal functions in addition to the basic material data. Adjusting these values requires material-specific tabulated data; and in some cases, such as with existing building materials, lab testing is required to obtain accurate hygrothermal performance data to input into the model.

Interior Boundary Conditions

Interior conditions may vary considerably based on building zone (Glass et al., 2013), and more than one model may be required to accurately study a whole building. In buildings where indoor humidity and temperature are explicitly controlled, the WUFI model should reflect anticipated conditions to the extent possible. WUFI has several methods for approximating interior conditions. BECs commonly use either a simplified format that models the annual indoor temperature and humidity as sinusoidal curves, or the ASHRAE 160 format, which requires inputs based on temperature and relative humidity setpoints, moisture generation, and air leakage through the building enclosure. With both formats, issues can arise due to the assumption of constant moisture generation and air leakage. In space types with variable conditions and mechanical schedules (e.g., convention space or auditorium) it is prudent to import a climate file with project-specific schedules. In the case of existing buildings, the modeler can import actual measured data from the space.

If interior conditions are unknown, ASHRAE 160 provides default design loads and parameters. Additionally, the ASHRAE Handbook of HVAC Applications contains typical interior temperature and RH values for different space types, which can be modeled in WUFI as sinusoidal curves; however, the Design Team should be made aware, in these cases, that the model may lack accuracy. Additional models may be required further along in the design phase, when more detailed information is known about the mechanical schedules in the proposed space.

Exterior Boundary Conditions

ASHRAE 160 requires exterior conditions to be simulated based on either 10 years of consecutive weather data or the moisture design reference year for the project location (Section 4.5). WUFI has a built-in database of weather files for a limited number of cities in North America and Western Europe; however, a user may also upload a weather file (e.g., TMY3 file), if available.

Interpretation of Results

In order to determine the risk of moisture-related concerns such as mold growth and corrosion, numerical data must be exported directly from WUFI and post-processed. ASHRAE 160 specifies a criterion for determining the level of biological growth on material surfaces called the "Mold Index," based on the updated mold growth model developed by Ojanen and colleagues (Glass et al., 2017). The Mold Index integrates time-based surface temperature and relative humidity with the mold sensitivity of the building material being evaluated (Glass et al., 2017). According to ASHRAE 160, the Mold Index shall not exceed three (threshold for visible biological growth) regardless of the sensitivity class (Section 6.1). Modelers often determine the Mold Index at any surface considered moisture-sensitive and at locations where condensation potential is the highest. Previous versions of ASHRAE 160 relied on a thirty-day running average of RH and temperature at the surface being analyzed to determine risk of biological growth. Based on industry experience and research, this criterion was deemed to be inconsistent with field observations and predicted failure in enclosure assemblies in which visible mold growth did not occur (Glass et al., 2017).

The thirty-day running average RH is still referenced by ASHRAE 160 with regard to corrosion potential. According to the standard, corrosion potential should be determined based on the properties of the metals specific to the enclosure assembly; however, if no such information is available, the thirty-day running average RH at the surface of the metal should remain below 80%.

Corrosion risk can vary greatly based on metal type and project-specific conditions and exposures (e.g., sulfate exposure or air pollution). Much like for the mold index, industry research is required to determine the accuracy of the predictive capabilities of the thirty-day running average for corrosion risk.

CONCLUSION

Continued advancement of computer modeling technologies has allowed designers greater ability to analyze heat, air, and moisture issues in building enclosure assemblies. More powerful and adaptive tools increase design flexibility and allow designers to predict in-service performance of proposed assemblies. Determining the appropriateness of a particular tool, however, requires experience, caution, and diligent effort to avoid common mistakes. By examining inputs and outputs and studying the field performance of enclosure assemblies, the industry can continue to improve model reliability. Different tools have various pitfalls and avenues for misuse. Often, experience and an understanding of likely results can help manage risk for modeling errors.

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