Development of a Moisture Risk Index for Wood-Frame Walls

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Abstract. This paper describes ongoing research toward the development of a moisture risk index that is intended to give a quantitative indication of the risk of moisture performance issues for different wood-frame wall assemblies in different climates. The concept is like a Home Energy Rating System Index but for moisture performance of a wall assembly rather than whole house energy performance. The moisture risk index is envisioned as providing more granularity than existing pass/fail criteria or green/yellow/red risk assessments while requiring less computational effort than full probabilistic analysis. Hygrothermal simulations and post-processor models for damage functions provide the core quantitative outputs that are used to construct the moisture risk index. Simulations are informed by field and laboratory data and include vapor diffusion, air leakage, and wind-driven rain loads. Damage functions include mold growth, fungal decay of wood, and corrosion of metal fasteners. The moisture risk index is based on scaling up the numerical outputs for the different damage functions, with an intended range from zero for the best performing (lowest risk) case to 100 for the worst performing (highest risk) case. The index will thus provide information about moisture risk that is easily understood by the building design and construction community, with the ability to illustrate how changing certain design features can mitigate risks.

Keywords: Wood · Moisture · Durability · Risk · Hygrothermal Simulation

1 Introduction

The building envelope performs several essential functions including prevention of bulk water intrusion and management of heat, air, and moisture [1, 2]. Moisture levels in buildings affect indoor air quality, the health and comfort of the occupants, and the serviceability of the structure. Hygrothermal simulation is an important tool that allows a user to predict moisture and temperature conditions within a building envelope assembly over time in response to interior and exterior environmental conditions [3–7]. This type of analysis can help identify and mitigate potential moisture performance risks prior to construction.

Simulation results typically include time series of temperature, relative humidity, and moisture content within a multilayered wall assembly. Interpretation of these results

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in terms of the risk of moisture issues is not straightforward. However, mathematical models have been developed that give a quantitative indication of the extent of certain types of damage, such as mold growth and fungal decay of wood, and corrosion of metal fasteners. Performance is typically evaluated using either pass/fail criteria or a broad categorical rating such as green (low risk), yellow (moderate risk), or red (high risk). An example of the pass/fail approach can be found in ASHRAE Standard 160 [7]. Categorical ratings have been used in various studies [8] and online tools including the Effective R Calculator [9] and the Building Science Advisor [10, 11].

This project aims to develop a more detailed, granular method for communicating risk than the pass/fail or green/yellow/red approaches discussed above. Although probabilistic analysis provides a wealth of information on risk, it requires knowing the statistical variation of each input parameter. In many cases, such detailed information is not available. Furthermore, probabilistic analysis requires much more time for running simulations and analyzing outputs. This paper describes the concept and progress toward the development of this moisture risk index.

2 Conceptual Overview of the Moisture Risk Index

The moisture risk index is intended to give the design and construction community a quantitative way of comparing the relative risk of moisture performance issues, such as mold growth, for different design options in different climates. The ability to compare options quantitatively sheds light on ways to mitigate risks and select more robust wall assemblies. As this research is still ongoing, we present the concept, progress thus far, and plans for work yet to be done.

The risk index will have a numerical scale from zero to 100. Conceptually the moisture risk index would be like a Home Energy Rating System (HERS) index, which is the industry standard for calculating energy performance of single-family residential buildings [12]. A reference home is assigned a HERS index of 100 and provides a baseline for comparison. Lower numbers indicate increasing energy efficiency. For example, a HERS index of 65 is 35% more efficient than the reference home. A HERS index of zero indicates a zero-energy home, one that produces as much energy through renewable sources as it consumes on an annual basis. The moisture risk index, however, would differ conceptually from the HERS index in several ways beyond the obvious difference between moisture risk and energy consumption. The moisture risk index would apply to a specific wall assembly, whereas the HERS index accounts for insulation levels and airtightness of the entire building envelope; the heating, ventilation, and air-conditioning system; and the water heating system. Furthermore, the moisture risk index is not intended to be based on a comparison to a reference wall in the way that the HERS index is based on a reference home.

A conceptually more relevant index is Scheffer's Decay Hazard index [13]. This index was developed based on monthly weather data, including temperature and precipitation, with the intent of giving the relative potential of a climate to promote decay of above-ground wood structures. While this index yields a useful quantitative comparison of different climates, it does not consider specific details of the wood structure. The moisture risk index would account for the design of the wall assembly as well as the climatic conditions and would be based primarily on the risk of mold growth, which typically occurs prior to wood decay.

The moisture risk index is intended to yield numbers based on quantitative output of hygrothermal simulations. The number would indicate the relative risk level for a particular wall assembly in a particular climate, not an absolute percentage of failure. The same wall assembly could thus have a different risk index in different climates. To the extent possible, the risk index should be consistent with historical experience of successes and failures known from forensic investigations and field measurements; that is, wall assemblies with proven performance over time in a particular climate should yield a relatively low risk index, whereas wall assemblies known to have problems should yield a relatively high risk index. A conceptual illustration of the development process involved in the risk index is shown in Fig. 1. The steps needed for development of the moisture risk index, along with the progress made, are detailed in the next section.

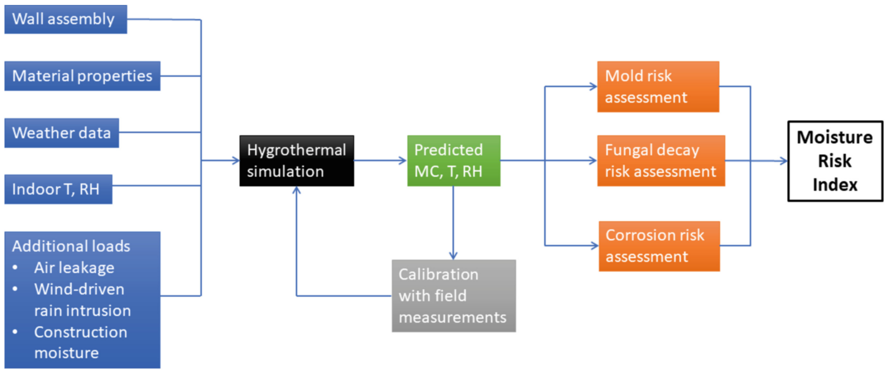

Fig. 1. Conceptual illustration of the development process for the moisture risk index (MC, moisture content; T, temperature; RH, relative humidity).

3 Progress Toward Development of the Moisture Risk Index

3.1 Hygrothermal Model Inputs

The development of the moisture risk index requires a wide range of inputs to yield a range of moisture performance for scaling the index. A variety of wall assembly configurations will be selected, consisting of different cladding materials, wood-based sheathing, exterior insulation, cavity insulation, and interior vapor retarders. In addition to walls expected to have robust moisture performance, we will select walls that are expected to have a high risk of moisture problems based on prior field studies and hygrothermal simulations.

Material property data for oriented strand board (OSB), asphalt-coated kraft paper, and latex paint on gypsum board have been evaluated in our lab [14]. Data for other materials will be obtained from the broader literature.

Geographic locations for the hygrothermal simulations will range from hot-humid to very cold. To the extent possible, performance will be evaluated using consensus-based moisture design loads. For each geographic location, the moisture design reference year will be used as defined by ASHRAE Standard 160 [7].

Indoor temperature will follow ASHRAE Standard 160 [7]. Many studies have shown that simulation results are sensitive to the choice of indoor humidity conditions [8, 15–17]. Two levels of indoor humidity will be used: a standard load following the intermediate method of ASHRAE Standard 160 [7], which corresponds to about a 68th percentile moisture generation rate [17], and a higher load representing a 90th percentile moisture generation rate [18].

Additional moisture loads include water vapor carried by air leakage, wind-driven rain infiltration, and construction moisture. Simulation approaches to include these loads will be adapted from prior literature [19–21].

3.2 Model Calibration with Field Data

It is important that the model correctly accounts for relevant physical phenomena and that the predictions are reasonably close to measured data. Finding agreement between simulations and measurements across different climates for a variety of wall assemblies is essential for development of the moisture risk index. For model calibration, the actual test conditions are needed, including weather data and indoor temperature and humidity, as opposed to design loads. In previous work, walls with OSB sheathing were monitored in a test structure in Madison, Wisconsin, with different combinations of interior vapor retarder and exterior insulation [22] using calibrated moisture pin readings [23]. Select material properties (see above) were measured to help tune and improve the models. All test walls included vinyl siding as the exterior cladding, 140-mm wood framing with fiberglass insulation, and interior gypsum board with latex paint. Interior vapor retarder was asphalt-coated kraft paper or polyethylene sheet. Types of exterior continuous insulation included 25 mm extruded polystyrene, 38 mm expanded polystyrene, and 38 mm mineral wool. Results show good agreement between simulations and experimental data; full details are provided in Ref [14]. This provides a validated model of these walls suitable for further parametric work in different climates. Calibrated models of other wall assemblies are still needed, which will rely on published field measurements in different climates.

3.3 Moisture-Related Damage Functions

Several mathematical models for assessing the risk of mold growth on building materials have been developed and improved over the past several decades [24–26]. We investigated the Mold Resistance Design (MRD) model [27] because of its simplicity and well-developed evaluation scale [28]. To tune this model for North American materials including OSB, plywood, and common wood species, we included laboratory mold growth data from Yang [29] to supplement the original European data for Scots pine and Norway spruce used for the MRD model. We made several modifications to the MRD model that yielded a modest improvement in predictive performance [30]. Exploration of more radical changes to the MRD model resulted in a new mold model, known as

Dose-Response Simple Isopleth for Mold (DR SIM), with improved predictive power [31]. An overview of the model logic is depicted in Fig. 2.

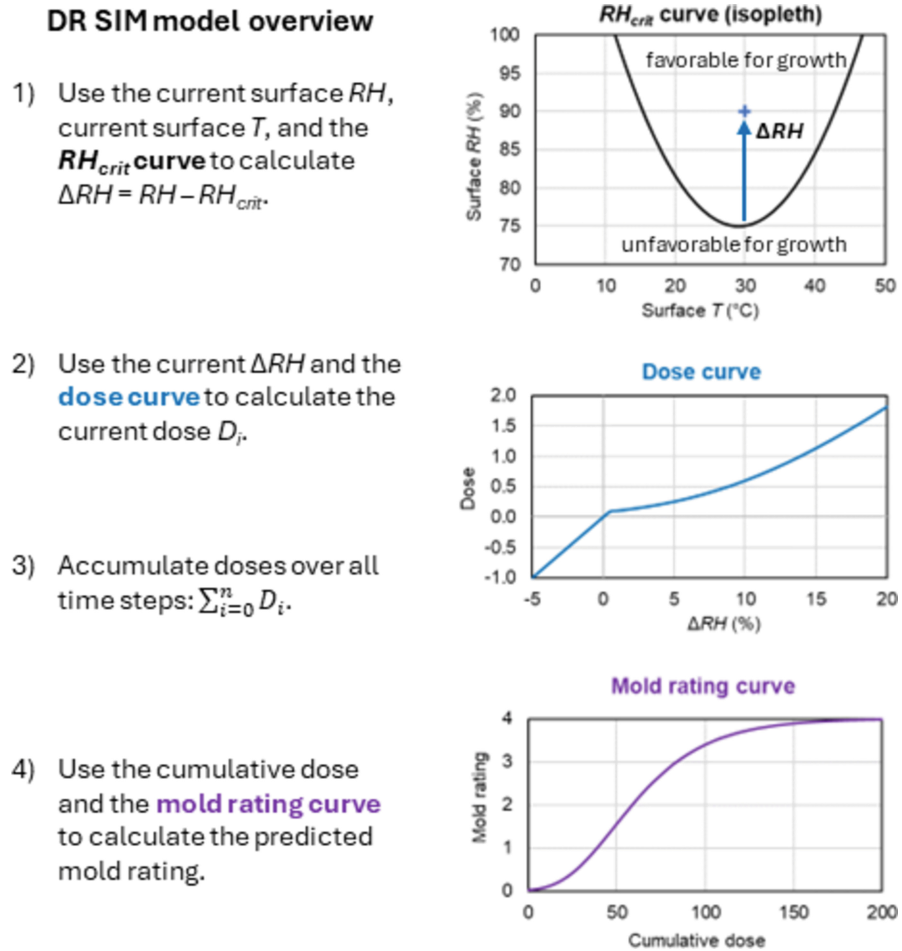

Fig. 2. Overview of the DR SIM model structure [31].

An isopleth marks the boundary at which mold growth begins; this critical relative humidity (RH_{crit}) is a function of temperature. The dose is calculated based on the difference between the current surface RH and RH_{crit}. The "response" is a predicted mold growth rating based on the cumulative dose and a sigmoidal growth curve. This model will be used as a key component in the moisture risk index.

In addition to mold growth on wood surfaces, fungal decay of wood and corrosion of metal fasteners embedded in wood will be explored as potential damage functions. Preliminary simulations combined with an empirical model for corrosion rate as a function of wood moisture content [32] indicate that mold growth is a much more significant risk than corrosion, such that the corrosion damage function is likely not needed in the overall risk index.

3.4 Development of the Numerical Moisture Risk Index

The calibrated hygrothermal model will be used to simulate different wall assemblies across a range of climates. This research is ongoing. Simulations will consider various aspects of moisture performance, in response to different moisture loads, as mentioned above. The output values of the hygrothermal simulations will provide the basis of the moisture risk index. A composite risk index will be developed based on scaling numerical values for mold risk and other potential damage mechanisms, such as fungal decay of wood and corrosion of metal fasteners. The scale is intended to range from zero (for the best performing case) to 100 (for the worst performing case). The overall risk index would reflect a composite of the various aspects of moisture performance in a way that is easily understood by the building design and construction community.

4 Conclusion

This paper describes the concept and ongoing research toward the development of a new index that is intended to communicate the relative risk of moisture performance issues for different wood-frame wall assemblies in various climates. This index is based on scaling up the numerical outputs for different damage functions, with an intended range from zero (for the lowest risk case) to 100 (for the highest risk case), thereby providing more detail than pass/fail or green/yellow/red approaches. The moisture risk index will provide information about moisture risk that is easily understood by the building design and construction community, with the ability to illustrate how changing certain design details can mitigate risks.

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