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Robust moisture reference year methodology for hygrothermal simulations

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ABSTRACT

Hygrothermal models allow designers to evaluate the hygrothermal performance of building envelopes. A key question in hygrothermal modeling however remains in the proper selection of representative exterior moisture conditions, *i.e.* a moisture reference year. A Climatic Index combining wind-driven rain load and potential evaporation is developed allowing considering the effect of climatic variability on the performance of the building envelope. The proposed Climatic Index combines thus both the wetting load and evaporation potential. This index is suitable for the evaluation of the level of moisture damage risk of wall assemblies where typical moisture problems are mainly caused by rainwater uptake or ingress.

The Climatic Index is determined for four cities in Switzerland. The hygrothermal performance of the assemblies is simulated and evaluated using a hygrothermal indicator, called the RHT Index. A clear correlation between Climatic Index and RHT Index is found. However, the moisture reference year selected based solely on a 10% level criterion of the Climatic Index may not correspond to the year with the most significant moisture damage risk. Therefore, a new procedure is proposed which combines a first selection of three years around the 10% level criterion, followed by a careful comparison of these years based on hygrothermal simulations and selection of the year with the largest RHT Index as moisture reference year. The combination of Climatic Index and RHT Index from hygrothermal simulations allows for the selection of moisture reference years that are around the 10% level, but excluding the ambiguity.

1. Introduction

Good hygrothermal performance of building envelopes is crucial as moisture damage is one of the main causes of building envelope deterioration. Excessive moisture accumulation in building envelopes may lead to structural damage, mold growth, decrease of thermal resistance of building materials and degradation of indoor air quality. An effective moisture control in the building envelope ensures building long-term service life [1]. It is essential for designers and builders to understand the moisture conditions of a climate region to assess correctly building envelope durability. Traditional steady-state methods such as Glaser [2] and dew point methods [3] cannot predict the long-term moisture response of a wall assembly, in particular when rainwater is taken up by the walls. Numerical hygrothermal models, simulating the coupled transport of heat and moisture over varying environmental conditions, have the ability to provide the data necessary to assess long-term heat and moisture performance of wall assemblies and predict the risk of moisture damage. But hygrothermal models require the selection of representative climatic data including rainfall, air temperature, relative humidity, solar radiation, long-wave radiation, wind speed and velocity as input, on yearly basis [4]. Representative climatic data should reflect the climatic variability subjected to the building envelope under consideration and provide the required level of safety with regard to moisture problems [5]. A common approach is to determine a reference year from available long-term climatic data.

Compared to energy reference years that use mean values of climate data for the locations under consideration [6–8], a moisture reference year should represent a climate that allows a correct evaluation of the moisture stress on the building envelope. Moisture problems are often caused by a combination of several extreme

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weather conditions. A 10% level criterion is often suggested to select moisture reference years. The choice of a 10% damage risk is justifiable, since this choice refers to a return period of 10 years, which for hygrothermal problems is appropriate, allowing the moisture accumulated during a bad year to dry out in the following years preventing long term deterioration [9]. Different methods have been used to define moisture reference years. Ali Mohamed and Hens [10] suggested that the critical moisture reference year (MRY) could be related with the annual mean outdoor temperature. By comparison, Geving [11] suggested that the MRY could be related to the annual mean outdoor relative humidity. Hagentoft and Harderup [12] presented that the MRY could be related to a Π factor, which describes the drying potential of a wall by defining the difference between the absolute humidity by volume at saturation and the actual absolute humidity by volume of the outdoor air. Kalamees and Vinha [5] used a method similar to a Π factor to select the MRY for evaluating the risk of water vapor condensation. In the above methods, the selection of the MRY is either based on a wetting potential or drying potential, not on both.

Cornick et al. [13] formulated a Moisture Index (MI) method to select MRY, which comprises both wetting and drying indices. The wetting index (WI) is based on the mean annual total horizontal rainfall or annual wind-driven rain load. The drying index (DI) represents the annual evaporation potential. It is defined as the sum of the hourly difference between the saturation vapor ratio and actual vapor ratio of the ambient air. As the wetting index and drying index have different units, they are normalized. The normalization scheme is given as follows:

$$I_{normalized} = (I - I_{\min})/(I_{\max} - I_{\min}) \quad (1)$$

where I represents the annual wetting index or drying index. $I_{\min}$ and $I_{\max}$ represent respectively the minimum and maximum annual wetting or drying index over the considered years.

The Moisture Index is calculated based on the normalized wetting and drying indices using the following equation:

$$MI = \sqrt{WI_{normalized}^2 + (1 - DI_{normalized})^2} \quad (2)$$

The advantage of the Moisture Index method is that it reflects actual environmental conditions as subjected to a wall during wetting or drying. However, there are several drawbacks with this method. Firstly, the drying potential is actually primarily influenced by the difference between the saturation vapor ratio at the wall surface and the water vapor ratio in the air, rather than the difference between saturation vapor ratio of the surrounding air and actual vapor ratio in the surrounding air as used in the MI method [14]. Secondly, wetting and drying potentials are very different physical quantities, showing different units. Finally, meteorological factors such as wind speed, short-wave solar radiation and long-wave radiation are not taken into account in the calculation of the drying index.

Therefore, an index with a more accurate representation of the drying process at the wall envelope surface is required. The drying of moisture from building envelopes occurs through evaporation. The evaporation process is affected by temperature, air humidity, wind speed, water availability and net radiation. Coming from soil science, the concept of potential evaporation is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation [15]. It is defined as the evaporation rate that occurs when a sufficient water source is available. Compared to actual evaporation, which is the quantity of water that is actually removed from a surface by evaporation, potential evaporation is independent of material type and structure and only depends on climatic conditions.

Moisture reference years can be selected based on the evaluation of different climatic variables. It is noted that the relation between the criteria for selecting a moisture reference year and the criteria for evaluating moisture performance is complex. Salonvaara et al. [16] stated that none of the existing methods for selecting a critical moisture reference year for hygrothermal simulations is satisfactory in terms of providing a known level of moisture performance using the RHT Index [17] to select moisture reference years that are among the most severe for the simulated structures.

The objective of this paper is to develop a methodology for the proper selection of moisture reference years required for hygrothermal performance studies. We propose the combined use of a Climatic Index for evaluating the climatic conditions and the RHT Index which allows the evaluation of the hygrothermal behavior. The Climatic Index comprises wetting and drying components, where the wetting component is based on the annual wind-driven rain load and the drying component on the annual potential evaporation. Hygrothermal simulations for four regions in Switzerland and for three different masonry wall systems are performed to predict temperature and moisture content distributions in the wall components. The RHT Index has been used to evaluate the hygrothermal performance of the different wall systems. The correlation between the Climatic Index and the RHT Index is evaluated. Moisture reference years are then selected using a combination of Climatic Index and RHT Index.

2. The Climatic Index approach

In general, the moisture conditions of building envelopes result from their wetting and drying behavior. A reference year for hygrothermal calculations should consider the critical climatic conditions which allow to evaluate the hygrothermal performance of a building envelope providing a required level of safety in terms of moisture damage. The moisture reference year should be selected by considering both wetting and drying components. Regarding the wetting component, wind-driven rain (WDR) is the largest moisture source that impacts durability of building envelopes. The orientation of the facade strongly affects the amount of wind-driven rain on the facade. Drying results from the evaporation of water from porous building materials to the surrounding air. Potential evaporation is a measure of the ability of the environment to remove water from the building envelope through the process of evaporation at its surface. Both wetting moisture load and evaporation potential are indispensable environmental factors for the evaluation of the hygrothermal behavior of building envelopes.

A Climatic Index can be considered to be a measure of the balance between the wetting and drying components. A simple way to evaluate the moisture stress on a facade is to compare wetting load to drying potential, dividing the annual wind-driven rain load by the annual potential evaporation, as follows,

$$Climatic\ Index = \frac{annual\ wind\ driven\ rain\ load}{annual\ potential\ evaporation} \quad (3)$$

The numerator represents the wetting component while the denominator represents the drying component. Therefore, a higher Climatic Index value represents a higher moisture risk for the building envelope. The Climatic Index considers the influence of façade orientation, net radiation, air temperature, air humidity, wind speed and direction as will be described below. Compared to the previously proposed Moisture Index [13], the proposed formulation in this paper does not need a normalization, since both wetting and drying components show the same units.